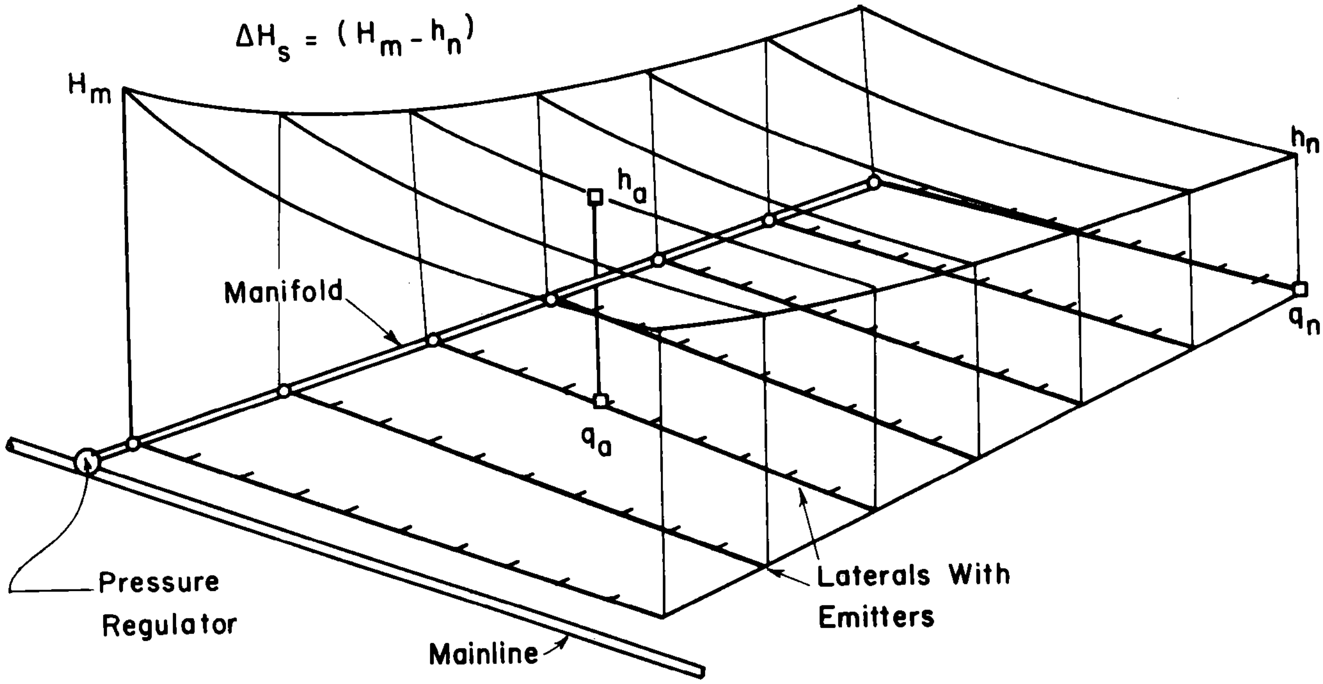

Figure 7-28.—Distribution of a pressure head in a subunit. ΔH_s = allowable pressure-head variation; H_m = manifold inlet pressure head; h_n = pressure head that gives the q_n required to satisfy the design emission uniformity; h_a = pressure head that gives the q_a; q_a = average or design emitter discharge rate; q_n = minimum emitter discharge.

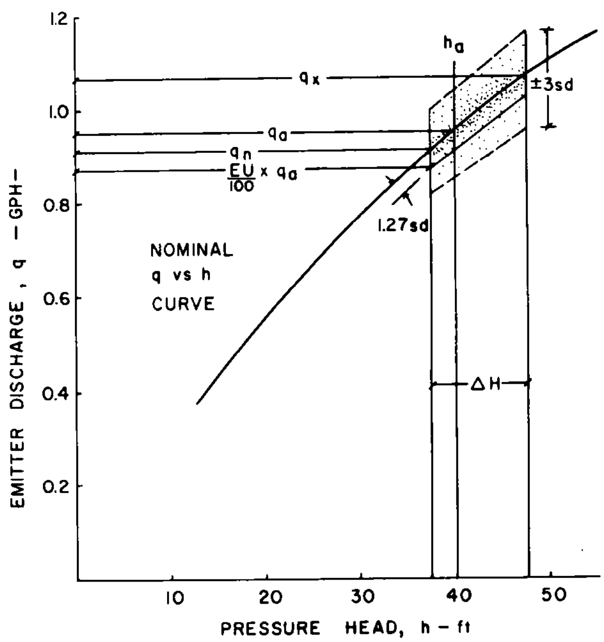

Figure 7-29.—Combined effect of pressure-head and manufacturing variations on discharges of individual emitters. h_a = pressure head that gives the average or design emitter discharge rate; sd = standard deviation; q_x = largest flow rate; q_a = average or design emitter discharge rate; q_n = minimum emitter discharge rate; EU = emission uniformity.

uniform irrigation; and (4) market values of the crop. An economic analysis of these factors can determine the optimal EU in any specific situation, but usually data are insufficient for such an analysis. For design purposes, the recommended ranges of EU values to use in conjunction with equation 7–33 are as follows:

1. For emitters in widely spaced permanent crops with:
   a. uniform topography, 90–94
   b. steep or undulating topography, 88–92
2. For emitters in closely spaced (<6 ft) permanent and semipermanent crops with:
   a. uniform topography, 86–90
   b. steep or undulating topography, 84–90
3. For line-source tubing on annual row crops with:
   a. uniform topography, 80–90
   b. steep or undulating topography, 70–85

The minimum emitter discharge that will satisfy the desired EU value (q_n) can be determined by solving equation 7–33 for q_n, i.e., using the q_a determined from equation 7–30 and the system coefficient of manufacturing variation (v_s) for the selected emitter and layout.

The pressure head that gives q_n for the selected emitter (h_n), feet, can be determined from equation 7–20. From h_a and h_n the $\triangle H_s$, feet, can be computed for design purposes by equation 7–34.

$$\triangle H_s = 2.5(h_a - h_n) \qquad \textbf{(7–34)}$$

Where

h_a = pressure head that will give the q_a required to satisfy equation 7–30, feet.
h_n = pressure head that will give the q_n required to satisfy equation 7–33 with the design EU, feet.

Maintaining the design EU requires keeping the pressure head between h_n and (h_n + $\triangle H_s$) while differentials in both pipe friction and elevation are included. If the calculated $\triangle H_s$ is too small for economic design purposes, the options are to (1) select another emitter that has a lower coefficient of manufacturing variation (v), discharge exponent (x), or both; (2) increase the number of emitters per plant (e); (3) use a different emitter or rearrange the system to get a higher h_a; or (4) relax the design EU requirement.

Total System Capacity

Knowledge of the total system capacity (Q_s), gallons per minute, is necessary to design an economical and efficient pumping plant and pipeline network. The system capacity for any emitter layout can be computed by equations 7–35a and 7–35b.

$$Q_s = 726 \frac{A}{N} \frac{eq_a}{S_p S_r} \qquad \textbf{(7–35a)}$$

Where

A = field area, acres.
e = number of emitters per plant.
N = number of operating stations.
q_a = average or design emission rate, gallons per hour.
S_p = plant spacing in the row, feet.
S_r = distance between plant rows, feet.

For uniformly spaced laterals that supply uniformly spaced emitters:

$$Q_s = 726 \frac{A}{N} \frac{q_a}{S_e S_l} \qquad \textbf{(7–35b)}$$

Where

S_e = spacing between emitters on a lateral, feet.
S_l = spacing between laterals, feet.

For computing total system capacity where line-source tubing is used and the discharge rate is per 100 ft of tubing, equation 7–36 can be used.

$$Q_s = 726 \frac{A}{N} \frac{e}{S_p} q_a \qquad \textbf{(7–36)}$$

Where

q_a = (q_a per 100 ft of tubing)/100.

Pump Operating Time per Season

The pump operating time per season (Q_t), hours, can be estimated by equation 7–37 with the gross seasonal volume (V_i), acre-feet, computed by equation 7–14 and the total system capacity (Q_s), gallons per minute.

$$Q_t = 5{,}430 \frac{V_i}{Q_s} \qquad \textbf{(7–37)}$$

Some systems require extra capacity because of anticipated slow changes in average emitter discharge (q_a) with time. Decreases in q_a can result from slow clogging from sedimentation in long-path emitters or compression of resilient parts in compensating emitters. Increases in q_a can result from mechanical or chemical fatigue of the flexible orifices in continuous- and periodic-flushing emitters or increases in minor leakage from fatigue in emitters and tubing.

Both decreases and increases in q_a necessitate periodic cleaning or replacement of emitters. A decrease in discharge rate can be compensated for by operating the system either at a higher pressure or for a longer time during each irrigation application. The need for frequent cleaning or replacement of emitters because of decreasing discharge rates can be prevented by designing the system with 10 to 20 percent extra capacity. By following the recommended design procedure, based on a maximum operation time of 21.6 hr/day during the peak use period, 10 percent extra capacity is already available. A possible alternative is to provide enough reserve operating pressure so that the pressure can be increased as required to hold q_a constant until the emitter discharge characteristics have degenerated by 10 to 20 percent.

Providing extra system capacity necessitates increasing the pump and pipe size, whereas providing reserve operating pressure requires only a slightly larger pump. Consequently, the cost of providing reserve pressure is less then the cost of providing extra capacity. Nonetheless, systems that have extra capacity can better make up for unavoidable interruptions before the emitter discharge has decreased. Furthermore, they can also handle situations when minor leakage increases q_a.

Net Water-Application Rate

The net water-application rate (F_n), inches per hour, is the water applied to the plants at the lowest discharge rate of the emission device. The application rate is important in irrigation scheduling because it is needed to calculate the number of hours that the system must operate to apply a specific volume of water.

The F_n is a function of the minimum expected rate of emitter discharge (q_n), gallons per hour, and thus cannot be computed until the hydraulic network has been designed. The q_n is a function of the minimum expected pressure head (h_n), feet, in the system and can be computed by equation 7–38.

$$q_n = q_a \left(\frac{h_n}{h_a}\right)^x \qquad \textbf{(7–38)}$$

Where

q_a = average emitter discharge, gallons per hour.
h_a = average pressure head of emitter, feet.
x = emitter discharge exponent.

If the friction head loss in a trickle irrigation system is greater than the head gain from elevation drops, h_n can be computed by equation 7–39.

$$h_n = (H_m - \triangle H_m - \triangle h) \qquad \textbf{(7–39)}$$

Where

H_m = manifold inlet pressure head, feet.
$\triangle H_m$ = difference in pressure head along the manifold, feet.
$\triangle h$ = difference in pressure head along the lateral, feet.

Steep downhill manifolds and laterals in which the friction loss is less than the head gain from elevation drops will have lower pressures at the inlet than further down the line. In such cases, h_n must be determined by inspection of the graphical solutions.

With an estimated q_n and the final design emission uniformity (EU), the F_n can be computed by equation 7–40.

$$F_n = 1.604 \frac{EU}{100} \frac{eq_a}{S_p S_r} \qquad \textbf{(7–40)}$$

Where

e = number of emitters per plant.
S_p = distance between plants in the row, feet.
S_r = distance between plant rows, feet.

The maximum daily net water application that the system can apply in an emergency is 24 hr × F_n.

Computing Injection of Fertilizer and Chemicals

The rate at which any concentration of chemical is to be injected into the irrigation water should be calculated carefully.

The rate of injecting fertilizer into the system (q_f), gallons per hour, depends on the concentration of the liquid fertilizer and the quantity of nutrients to be applied during the irrigation. The rate can be computed by equation 7–41.

$$q_f = \frac{F_r A}{H F_c H_r} \qquad \textbf{(7–41)}$$

Where

F_r = fertilizer rate (quantity of nutrients to be applied per irrigation cycle), pounds per acre.

H = time of irrigating per irrigation cycle, hours.
A = area irrigated per irrigation cycle, acres.
H_r = ratio between hours of fertilizing and hours of irrigating per irrigation cycle.
F_c = concentration of nutrients in the liquid fertilizer, pounds per gallon.

Capacity of the fertilizer tanks.—The capacity of the fertilizer tanks is an important consideration. Large, low-cost tanks are practical for use with injection pumps. A large tank is a good place to store fertilizer for periods when supply is short, and its use reduces the labor associated with frequent filling. If a large tank is being used, shutoff is a convenient way to control the amount of fertilizer injected.

For a pressure-differential injection system, a high-pressure fertilizer tank should hold enough for a complete application. Required tank capacity (C_t), gallons, can be computed by equation 7–42.

$$C_t = \frac{F_r A}{F_c} \qquad \textbf{(7–42)}$$

Where

F_r = fertilizer rate (quantity of nutrients to be applied per irrigation cycle), pounds per acre.
A = area irrigated per irrigation cycle, acres.
F_c = concentration of nutrients in the liquid fertilizer, pounds per gallon.

Rate of injecting chlorine or acid.—The rate of injecting chlorine or acid depends on the system's flow rate. Liquid chlorinators are usually preferred over gas chlorinators because:

1.. A gas chlorinator is used for chlorination only, whereas a positive displacement pump can inject not only liquid chlorine and fertilizers, but also micronutrients, fungicides, herbicides, acids, and other liquids as needed.

2. A gas chlorinator usually costs 4 to 10 times as much as a pump.

3. Because chlorine gas is extremely hazardous, it is expected that, for installing a gas chlorinator, the Occupational Safety and Health Administration (OSHA), will require the use of a separate building and special handling of the gas cylinders.

4. Most manufacturers of trickle irrigation hardware make filtration equipment and provide the chemical solution tanks and chemical injection systems as part of their systems for filtration, water treatment, and chemical feeding.

The rate of injecting a chemical such as chlorine or acid (q_c), gallons per hour, can be calculated by equation 7–43.

$$q_c = \frac{0.006CQ_s}{csg} \qquad \textbf{(7–43)}$$

Where

C = desired dosage, parts per million.
Q_s = irrigation system capacity, gallons per minute.
c = concentration of the desired component in liquid chemical concentrate, percent.
sg = specific gravity of the chemical concentrate.

Pipeline Hydraulics

This section contains data and information about the hydraulic aspects of pipe systems important in the design of trickle irrigation systems. For more general information on the subject, refer to Section 5, Hydraulics, of this National Engineering Handbook.

Friction Loss in Pipelines

Plastic is the predominant pipe material used for trickle irrigation laterals, manifolds, and main lines. The Hazen-Williams formula is the basis for many friction-loss calculations. Equation 7–44 can be used to calculate the head loss gradient (J), feet per 100 feet, by the Hazen-Williams formula.

$$J = \frac{h_f 100}{L} = 1{,}050 \frac{\left(\frac{Q}{C}\right)^{1.85}}{D^{4.87}} \qquad \textbf{(7–44)}$$

Where

h_f = head loss from pipe friction, feet.
L = pipe length, feet.
Q = flow rate in the pipe, gallons per minute.
C = friction coefficient for continuous sections of pipe.
D = ID of the pipe, inches.

Typically, C = 150 has been used to calculate friction losses in plastic pipe. The inner surface of plastic pipe is very smooth, and the C value of 150 is recommended for smooth pipes in Hazen-Williams tables.

The Hazen-Williams formula was developed from study of water distribution systems that used 3-in. or larger diameter pipes and discharges greater than 50 gpm. Under these flow conditions, the Reynolds number (N_R) is greater than 5×10^4, and the formula predicts friction loss satisfactorily.

However, for the smaller pipe, such as the typical ½-in. lateral hoses used in trickle irrigation systems, the Hazen-Williams formula with C = 150 underestimates the friction losses by about 30 percent. This phenomenon is demonstrated by figure 7–30, which shows laboratory test results for plain ½-in. trickle hose (0.58-in. ID) superimposed on the Moody diagram. The N_R for 70°F water flowing through a pipe can be computed by equation 7–45.

$$N_R = 3{,}214 \frac{Q}{D} \tag{7–45}$$

The Darcy-Weisbach friction factor (f) in the Moody diagram is related to h_f by the Darcy-Weisbach formula, equation 7–46.

$$h_f = f \frac{L}{D} \frac{v^2}{2g} \tag{7–46}$$

Where

v = velocity of flow in the pipe, feet per second.
g = acceleration of gravity (32.2 ft/s²).

The "smooth pipe" line on the Moody diagram is generally considered the ultimate in pipe smoothness. For comparison, the "equivalent" f values for Hazen-Williams C values of 130, 140, and 150 are plotted on figure 7–30. The position of the C-value lines clearly shows a discrepancy in the "smooth pipe" concept in this range of Reynolds numbers. The C = 150 line, which represents Hazen-Williams smooth pipes, is well below the friction factor of

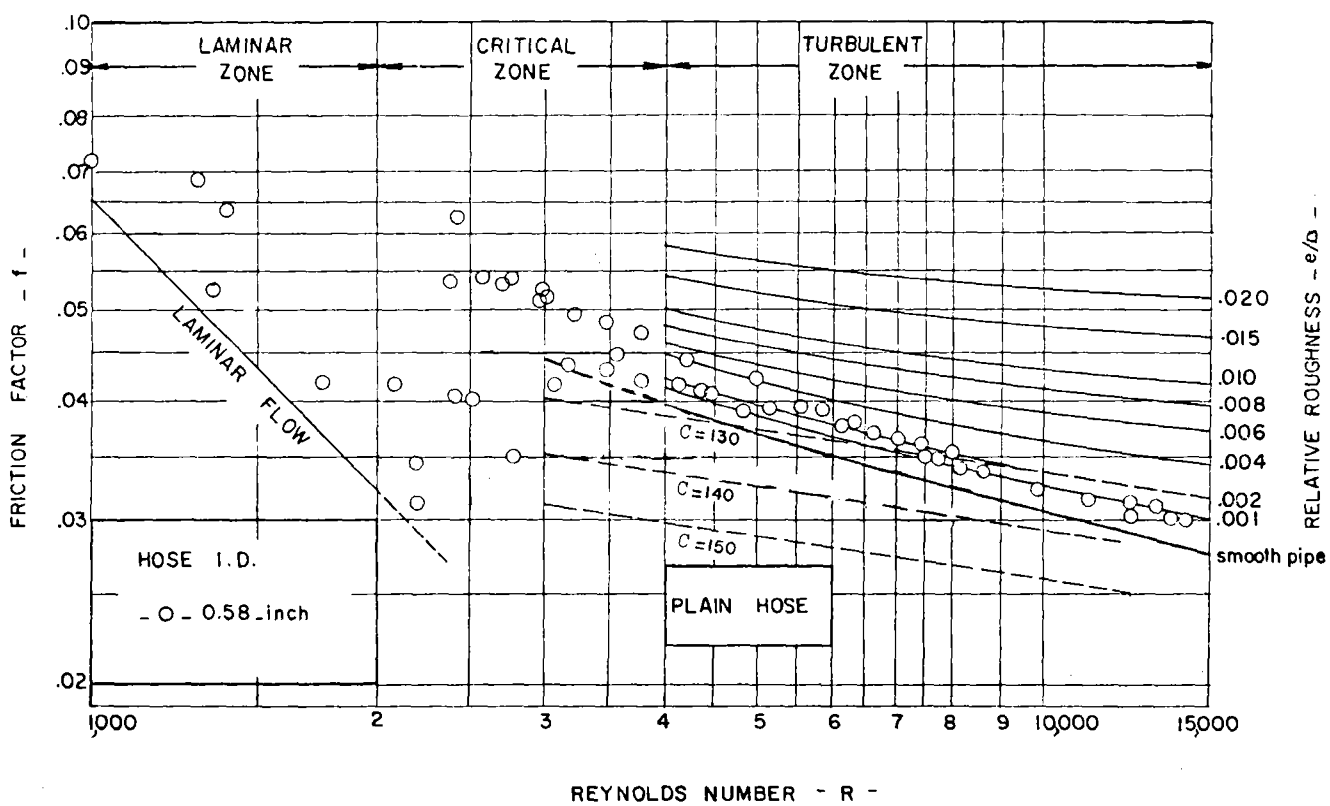

Figure 7–30.—Darcy-Weisbach f values for 1/2-in. (0.58-in. inside diameter) trickle irrigation hose.

Darcy-Weisbach smooth pipes. The range of Reynolds numbers shown represents hose discharge rates between 0.2 gpm and 3.0 gpm for ½-in. hose. The ½-in. hose exhibits characteristics somewhat above the Moody "smooth pipe" line and equivalent to an average C value of about 130. Note that the data points fall on lines generally parallel to the lines on the Moody diagram rather than on constant C-value lines. This observation strongly supports the conclusion that the Darcy-Weisbach formula represents the friction losses in hoses better than does the Hazen-Williams formula.

Pipe friction loss tables.—Tables of friction loss encountered in the common sizes of lateral hose and PVC thermoplastic pipe used for trickle irrigation systems are presented in Appendix B. These tables of pipe friction loss are based on the Darcy-Weisbach formulas and assume smooth pipe. The need for time-consuming interpolation is reduced by using small flow increments. The PVC pipes presented are for the lowest standard dimension ratio (SDR) (or pressure rating) iron pipe sizes (IPS) presented in the SCS standard for "Irrigation Water Conveyance Pipeline."[4] The friction tables were developed by computer, using equations 7–47a and 7–47b to compute f.

For $N_R < 2{,}000$:

$$f = \frac{64}{N_R} \qquad \textbf{(7–47a)}$$

and for $N_R \geq 2{,}000$:

$$\frac{1}{\sqrt{f}} = 0.80 + 2.0 \log (N_R\sqrt{f}) \qquad \textbf{(7–47b)}$$

Friction loss computations.—Equation 7–47b is quite tedious to use for desk computation of friction losses. The Blasius formula (equation 7–48), accounts for the low range in N_R in trickle irrigation systems. Equation 7–48 can be used for computing friction losses for N_R between 2,000 and 100,000.

$$f = 0.32\, N_R^{-0.25} \qquad \textbf{(7–48)}$$

The computation of J may be simplified by combining equation 7–45, 7–46, and 7–48 and adjusting the constant for average conditions. Equation 7–49a can be used to compute J for 5-in.-diameter or smaller plastic pipes and hoses. For D < 5 in.:

$$J = \frac{h_f 100}{L} = 0.133 \frac{Q^{1.75}}{D^{4.75}} \qquad \textbf{(7–49a)}$$

Equation 7–49b can be used to compute J for larger diameter plastic pipe. For D > 5 in.:

$$J = \frac{h_f 100}{L} = 0.100 \frac{Q^{1.83}}{D^{4.83}} \qquad \textbf{(7–49b)}$$

Equations 7–49a and 7–49b are as easy to use as the Hazen-Williams formula, and they more accurately predict friction loss for 70°F water flowing in smooth plastic pipe.

Head Losses Through Fittings

Equation 7–49 is developed for smooth plastic pipe without fittings. The three conventional methods for computing the additional pressure-head losses from special equipment, valves, and pipe and fittings are: (1) graphing friction loss vs. flow rate, (2) expressing the added pressure-head loss as the length of pipe (of the same diameter) that would give the same loss, and (3) expressing the loss in terms of a velocity head coefficient. Equation 7–50 can be used for computing friction head loss caused by a specific fitting (h_e), feet.

$$h_e = K_f \frac{V^2}{2g} \qquad \textbf{(7–50)}$$

Where

K_f = friction head-loss coefficient for a specific fitting.
$V^2/2g$ = velocity head, which is the energy head from the velocity of flow, feet.

Graphs, equivalent lengths, or K_f values should be supplied by manufacturers or taken from handbooks on hydraulics. Usually the losses attributed to standard pipe fittings are small and can be grouped in a miscellaneous friction-loss safety factor as shown under Samples of Trickle Irrigation System Designs, Drip System.

Emitter-connection loss equivalent lengths (f_e), feet, representing losses for different barb sizes and lateral diameters are shown in figure 7–23, which

[4]Soil Conservation Service, U.S. Dep. Agric. 1977–81. National Handbook of Conservation Practices.

should be used when the manufacturer does not provide emitter-connection loss data. For computing the friction head loss, the equivalent length of the lateral with emitters (l'), feet, can be computed by equation 7–51a and substituted for the actual length of the lateral with emitters (l), feet.

$$l' = l\left(\frac{S_e + f_e}{S_e}\right) \tag{7-51a}$$

Where

S_e = spacing between emitters on the lateral, feet.

In graphic analysis of lateral head loss, increasing the equivalent head-loss gradient of the lateral with emitters (J') is a convenient way to account for the emitter connection roughness, and J', feet per 100 feet, can be computed by equation 7–51b.

$$J' = J\left(\frac{S_e + f_e}{S_e}\right) \tag{7-51b}$$

Where

J = head loss gradient of the lateral with emitters, feet per 100 feet.

Multiple-Outlet Pipeline Losses

Head loss from pipe friction (h_f) in laterals and manifolds that have evenly spaced outlets and uniform discharge from each outlet can be estimated by equation 7–52.

$$h_f = J'FL/100 \tag{7-52}$$

Where

J' = equivalent head-loss gradient of the lateral with emitters, feet per 100 feet.
F = reduction coefficient to compensate for the discharge along the pipe.
L = pipe length, feet.

Table 7–6 gives F values for various numbers of openings along the pipe. The F values are given for use with both the Hazen-Williams formula (flow rate exponent 1.85) and the Darcy-Weisbach tables or equation 7–49a (flow rate exponent 1.75). The F values were computed by dividing the actual computed loss in multiple-outlet pipelines (with equal discharge per outlet) by the head loss in pipelines of equal diameter and length but with only one outlet.

Dimensionless Pipe-Friction Curve

The head loss along any multiple outlet pipeline that has uniform outlet spacing and discharge can be represented by a single line as a dimensionless plot. Figure 7–31 shows such a plot when the horizontal scale is a dimensionless ratio of any position (x), feet, along the length divided by the total length of the multiple-outlet pipeline (L), feet. The vertical axis represents the head loss from pipe friction (h_f), feet, divided by L/100. This general friction curve can be adapted to a specific problem by setting the intercept of the friction curve (at $x/L = 1.0$) equal to $J'F$ for a specific lateral or manifold pipe diameter, flow rate, number of outlets, and length.

Table 7–6.—Reduction coefficient (F) for multiple-outlet pipeline friction-loss computations in which the first outlet is a full spacing from the pipe inlet

Number of outlets	F 1.85[1]	F 1.75[2]	Number of outlets	F 1.85[1]	F 1.75[2]
1	1.00	1.00	9	0.41	0.42
2	0.64	0.65	10–11	0.40	0.41
3	0.54	0.55	12–15	0.39	0.40
4	0.49	0.50	16–20	0.38	0.39
5	0.46	0.47	21–30	0.37	0.38
6	0.44	0.45	31–70	0.36	0.37
7	0.43	0.44	>70	0.36	0.36
8	0.42	0.43			

[1]The flow rate exponent of 1.85 is for use with the Hazen-Williams formula.
[2]The flow rate exponent of 1.75 is for use with tables based on the Darcy-Weisbach equation and smooth-pipe curve on the Moody diagram or with equation 7–49a.

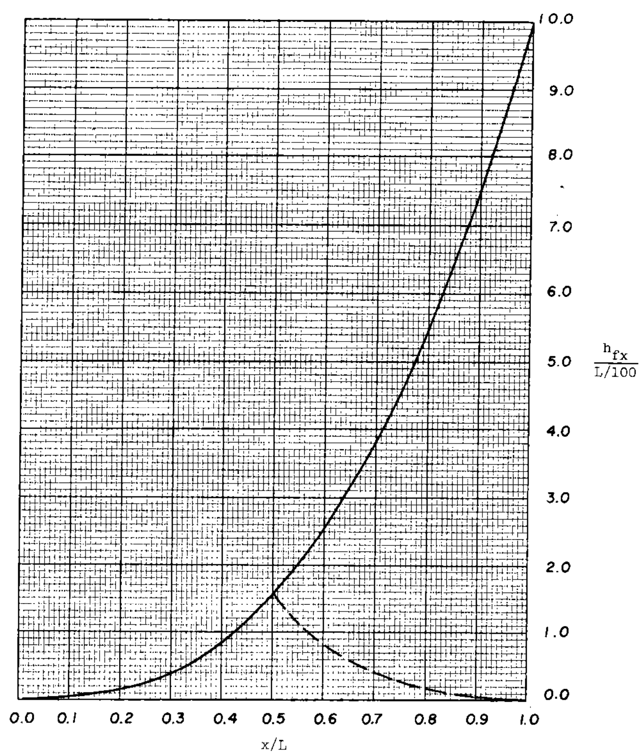

Figure 7–31.—General friction curve for a multioutlet pipeline that has uniform diameter, uniform spacing between outlets, and uniform flow per outlet. X = any position along the length, feet; L = total length, feet; h_{fx} = head loss from position x to the closed end, feet.

The shape of the general friction curve can be plotted from an outlet-by-outlet analysis of a typical multiple-outlet line. It can also be determined mathematically by equation 7–53.

$$\frac{h_{fx}}{L/100} = J'F(\frac{x}{L})^{2.75} \qquad \textbf{(7–53)}$$

Where

h_{fx} = head loss from position x to the closed end, feet.
J' = equivalent head-loss gradient of the pipe with emitters, feet per 100 feet.
F = reduction coefficient to compensate for the discharge along the pipe.
x = distance from the closed end, feet.

Equation 7–53 can be derived mathematically by first combining equations 7–49a, 7–51b, and 7–52 to obtain:

$$h_f = \frac{L}{100} F (\frac{S_e + f_e}{S_e}) 0.133 \frac{Q^{1.75}}{D^{4.75}}$$

Where

h_f = head loss from pipe friction, feet.
S_e = spacing between emitters on a lateral, feet.
f_e = emitter-connection loss equivalent length, feet.
Q = flow rate in the pipe, gallons per minute.
D = ID of the pipe, inches.

Then L is replaced with x and Q with Qx/L to obtain the h_{fx} at any point x from the closed end, and both sides are divided by L to obtain the dimensionless expression:

$$\frac{100h_{fx}}{L} = \frac{x}{L} F (\frac{S_e + f_e}{S_e}) 0.133 \frac{[(x/L)Q]^{1.75}}{D^{4.75}}$$

Equation 7–53 can now be obtained by combining terms and noting that:

$$J' = \frac{S_e + f_e}{S_e} 0.133 \frac{Q^{1.75}}{D^{4.75}}$$

The mathematical derivation of equation 7–53 assumes that F is a constant between the end and any point in the multiple-outlet pipeline. This assumption is obviously not true, but on pipelines that have 12 or more outlets the error is less than 5 percent.

Equation 7–53 can also be derived graphically from a plot of x/L vs. $h_{fx}/(L/100)$ data obtained from an outlet-by-outlet analysis of a multiple-outlet pipeline. Table 7–7 gives a set of data developed from a hydraulic analysis of multiple-outlet pipeline. The dimensionless friction-loss values have been adjusted so that 100 H_{fx}/L = 10.00 at x/L = 1.0. These data are useful for plotting curves such as figure 7–31 with different scales.

Economic Pipe-Size Selection

The economics of trickle irrigation is very important to management in modern agriculture. The essence of economic selection of pipe size for a main line is to find the minimum sum of fixed costs plus operating costs on either a present-worth or an an-

Table 7–7.—Dimensionless data for plotting friction curves for multiple-outlet pipelines[1]

x/L	100 h_{fx}/L	x/L	100 h_{fx}/L
0.10	0.02	0.60	2.45
0.20	0.13	0.65	3.05
0.25	0.23	0.70	3.74
0.30	0.37	0.75	4.52
0.35	0.57	0.80	5.40
0.40	0.81	0.85	6.38
0.45	1.12	0.90	7.47
0.50	1.49	0.95	8.68
0.55	1.93	1.00	10.00

[1]x = distance from the closed end, feet; L = length of the multiple-outlet pipeline, feet; h_{fx} = head loss from position x to the closed end, feet.

nual basis as presented pictorially in figure 7–32. Usually it is sufficient to represent this sum by the cost of the pipe in place and the energy cost (in terms of the fuel required by the pumping plant) of pressure lost in pipe friction.

Although the selection of economical pipe sizes is an important engineering decision, it is often given insufficient attention, especially in designing relatively simple irrigation systems, because the methods of selection are considered too time consuming, limited, or complex. The economic pipe-size selection chart (fig. 7–33) was developed to simplify the pipe-sizing process for manifolds and main lines for PVC pipe with lowest SDR (or pressure rating) IPS pipe sizes.

Life-Expectancy Costs

To determine the most economical life-expectancy cost of a system, find the minimum fixed-plus-operating costs. Visualize the problem by thinking of selecting the diameter of a water supply line. If a very small pipe is used the initial cost will be low, but the operating (energy-for-power) cost for overcoming friction losses in the pipe will be large. As the pipe diameter increases, the fixed costs increase, but the power costs decrease. The optimum pipe size, where the sum of the fixed costs plus power costs is at a minimum, is illustrated in figure 7–32.

The concept of value engineering represented by figure 7–32 can be used for the life-expectancy costs of more complex systems by taking into account all of the potential fixed costs such as various types of basic hardware, land preparation, mechanical additions, and automation. These fixed costs can then be added to the full set of operating costs, including energy, labor, maintenance, and management.

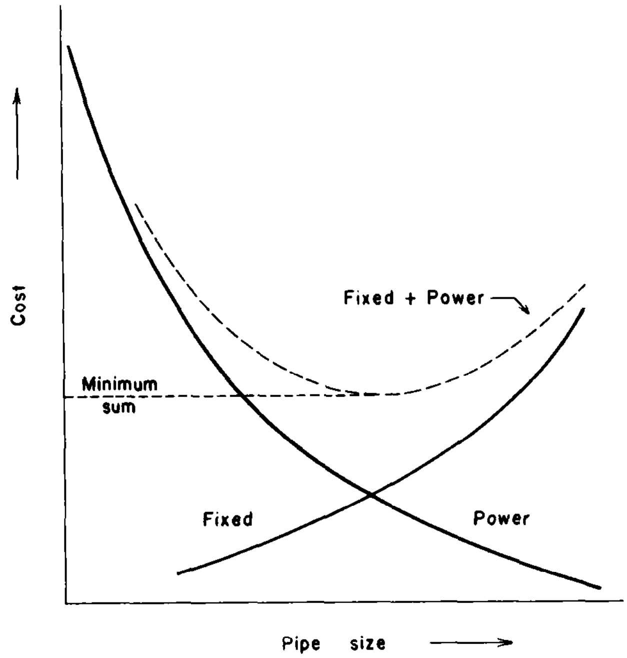

Figure 7–32.—Influence of pipe size on fixed, power, and total costs.

The life-expectancy cost can be analyzed on a capital value or on an annual value. In either analysis the interest rate (i), the expected life of the item (n), and the estimated annual rate of increase in energy costs (r) must be considered. Table 7–8 lists the necessary factors for either a present-worth or an annual life-expectancy cost analysis, assuming a 9-percent annual rise in energy costs, for 10- to 25-percent interest rates and 7- to 40-year life expectancies.

The present worth factor of the rising energy cost [PW(r)] and the equivalent annual factor of the rising energy cost [EAE(r)] were computed by equations 7–54 and 7–55 for r ≠ i.

$$PW(r) = \left[\frac{(1+r)^n - (1+i)^n}{(1+r) - (1+i)}\right] \times \left[\frac{1}{(1+i)^n}\right] \qquad \textbf{(7–54)}$$

and

$$EAE(r) = \left[\frac{(1+r)^n - (1+i)^n}{(1+r) - (1+i)}\right] \times \left[\frac{i}{(1+i)^n - 1}\right] \qquad \textbf{(7–55)}$$

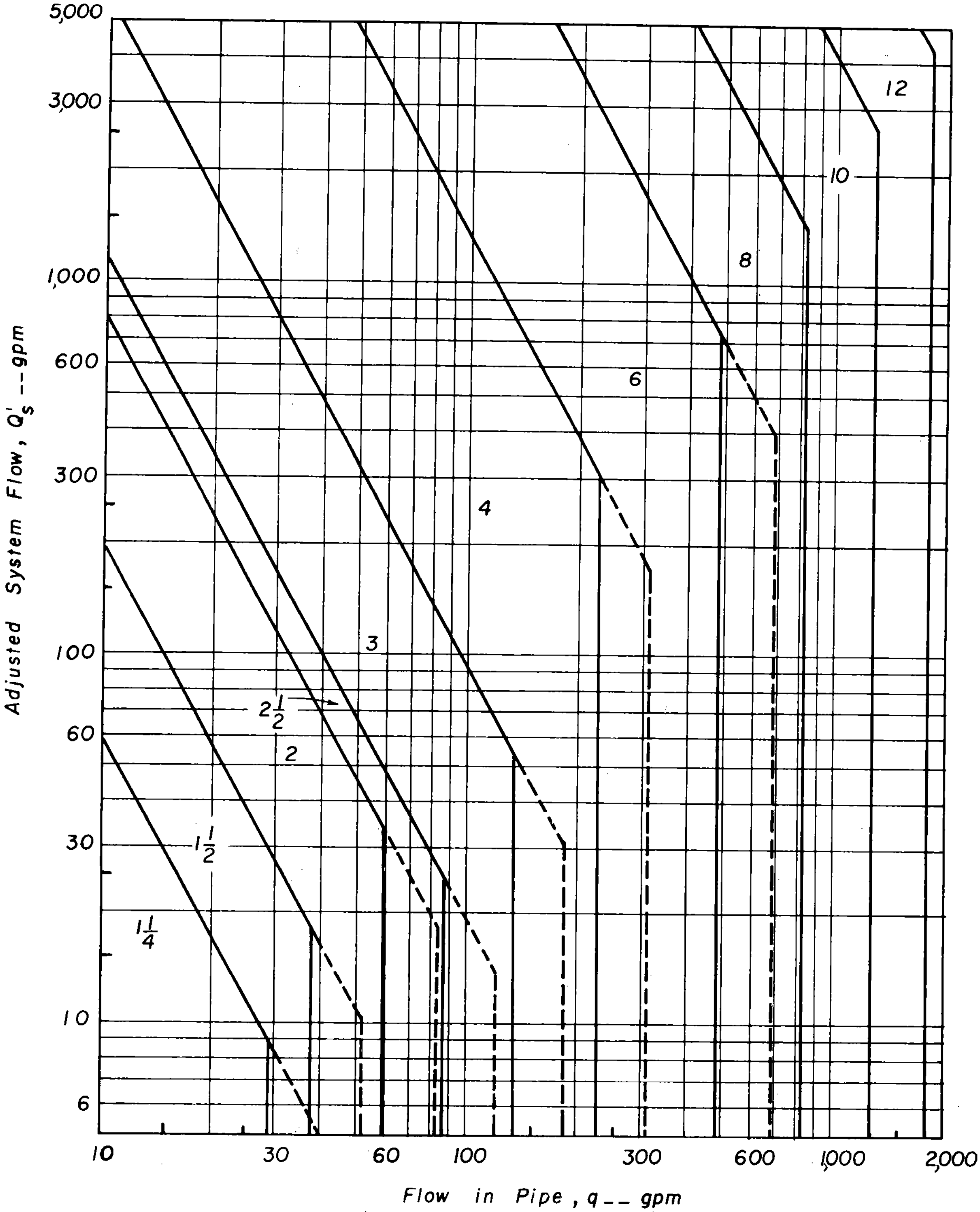

Figure 7–33.—Economic pipe-size selection chart for polyvinyl chloride thermoplastic IPS (iron pipe size) pipe having minimum acceptable SDR (standard dimension ratio) ratings. (Solid and dashed vertical lines, respectively, represent 5 to 7 ft/s velocity limitations.)

Table 7–8.—Present-worth and annual economic factors for an assumed 9-percent annual rise in energy costs with various interest rates and life expectancies

Interest (i), %[1]	Factor	Factor value with indicated life expectancy (n), years: 7	10	15	20	30	40
10	PW(9%)[2]	6.193	8.728	12.802	16.694	23.964	30.601
	EAE(9%)[3]	1.272	1.420	1.683	1.961	2.542	3.129
	CRF[4]	0.205	0.163	0.132	0.118	0.106	0.102
	PW(0%)[5]	4.868	6.145	7.606	8.514	9.427	9.779
15	PW(9%)	5.213	6.914	9.206	10.960	13.327	14.712
	EAE(9%)	1.253	1.378	1.574	1.751	2.030	2.215
	CRF	0.240	0.199	0.171	0.160	0.152	0.151
	PW(0%)	4.160	5.019	5.848	6.259	6.566	6.642
20	PW(9%)	4.453	5.615	6.942	7.762	8.583	8.897
	EAE(9%)	1.235	1.339	1.485	1.594	1.724	1.781
	CRF	0.277	0.239	0.214	0.205	0.201	0.200
	PW(0%)	3.605	4.193	4.676	4.870	4.979	4.997
25	PW(9%)	3.854	4.661	5.449	5.846	6.147	6.224
	EAE(9%)	1.219	1.306	1.412	1.479	1.539	1.556
	CRF	0.316	0.280	0.259	0.253	0.250	0.250
	PW(0%)	3.161	3.571	3.859	3.954	3.995	4.000

[1]Interest is the time value of unsecured money to the developer.
[2]PW(9%) is the present-worth factor of the rising cost of energy, taking into account the time value of money over the life expectancy.
[3]EAE(9%) is the equivalent annual factor of the rising cost of energy, taking into account the time value of money over the life expectancy.
[4]CRF is the uniform-series annual payment (capital recovery factor), taking into account the time value of money and the depreciation of equipment over the life expectancy.
[5]PW(0%) is the present-worth factor of the constant cost of energy, taking into account the time value of money over the life expectancy.

The standard capital-recovery factor (CRF) was computed by equation 7–56.

$$CRF = \frac{i(1 + i)^n}{(1 + i)^n - 1} \qquad (7\text{–}56)$$

In the consideration of life-expectancy cost, the time value of unsecured money to the developer should be used as the appropriate i value in equations 7–54, 7–55, and 7–56. This rate is normally higher than bank interest rates because of the higher risks involved. For unsecured agricultural developments, the interest rates of high-grade, long-term securities should be doubled unless special tax benefits are involved.

The n of properly designed and installed PVC pipe should be 40 years. However, because of obsolescence, n values of 20 or less are frequently used. The number of brake horsepower (BHP) hours per unit of fuel that can be expected from efficient power units is as follows:

Diesel fuel	15.0 BHP hr/U.S. gal
Gasoline (water cooled)	10.5 BHP hr/U.S. gal
Tractor fuel	8.5 BHP hr/U.S. gal
Butane-propane	9.5 BHP hr/U.S. gal
Natural gas	8.5 BHP hr/100 ft^3
Electricity	1.2 BHP hr/kWh @ meter

From table 7–8 some interesting observations can be made concerning the long-term effects of rising energy costs:

1. Low i values deemphasize high first costs, as indicated by low CRF's.
2. Low i values emphasize rising energy costs, as indicated by high PW(9%)'s and EAE(9%)'s, but have less effect on constant energy costs, as indicated by PW(0%)'s.
3. High i values emphasize high first costs, but deemphasize energy costs.
4. Long useful life deemphasizes high first costs, but emphasizes energy costs.
5. Rising energy costs have a maximum effect when i is low and n is high.

6. The relative effect of rising vs. constant energy costs can be observed by comparing PW(9%) to PW(0%) or EAE(9%) to EAE(0%) = 1.0 for any n and i.

The factors presented in table 7–8 can be used with the present annual power costs (E) and the cost of the irrigation system (C) to estimate the following:

1. The present worth of the rising (9 percent per year) annual energy cost, E × PW(9%).
2. The equivalent annual cost (E′) of the rising (9 percent per year) energy cost, E × EAE(9%).
3. The annual fixed cost of the irrigation system, C × CRF.
4. The present worth of the constant energy cost, E × PW(0%).
5. The annual cost of the constant energy cost, E.
6. The present worth of the irrigation system, C.

Economic Pipe-Selection Charts

Development.—Figure 7–33 was developed for PVC thermoplastic pipe with the lowest SDR (or pressure rating) IPS pipe sizes presented in the SCS Standard "Irrigation Water Conveyance Pipeline." (These are the same pipe sizes for which friction loss tables are presented in Appendix B.) The chart can be adjusted for a given set of economic conditions and entered to directly select the most economical pipe sizes for nonlooping systems with a single pump station. The following example demonstrates how the chart is constructed, so that charts for PVC pipe of other sizes or wall thicknesses can be developed.

Step 1—Assume: cost recovery factor (CRF) = 0.100; cost per water horsepower per year (C_{whp}) = \$100.00; and PVC pipe cost = \$1.00/lb. Obtain the ID and weight per foot of pipe of each size being considered. This example shows construction of the line separating the 3- and 4-in. regions.

The ID and weight of 3-in. SDR 32.5 pipe are 3.284 in. and 74.2 lb/100 ft, respectively, and those of 4-in. SDR 41 pipe are 4.280 in. and 98.4 lb/100 ft, respectively.

Step 2—Determine the yearly fixed-cost differences between adjacent 3- and 4-in. pipes with CRF = 0.100:

$$0.100(\$98.4 - \$74.2) = \$2.42/100\text{ ft}$$

Step 3—Determine the water horsepower savings needed to offset the annual fixed-cost difference between adjacent 3- and 4-in. pipes with C_{whp} = \$100.00:

$$\frac{\$2.42/100\text{ ft}}{\$100.00} = 0.0242\text{ whp/100 ft}$$

Step 4—Assume a convenient system flow rate (Q_s') and compute the difference in head loss between the adjacent pipe of different sizes ($h_{f(a,b)}$) needed to obtain the water horsepower savings computed in step 3. Assuming a Q_s' of 100 gpm for the 3- and 4-in. pipe sizes:

$$h_{f(3,4)} = \frac{0.0242\text{ whp/100 ft} \times 3{,}960}{100\text{ gpm}}$$

$$= 0.958\text{ ft/100 ft}$$

Step 5—Determine the rate of pipe flow that will produce the required $h_{f(a,b)}$ between adjacent pipe of different sizes. These flow rates can be determined by trial and error with head loss gradient (J) values from calculation of pipe friction loss or from tables of friction losses. Using the friction loss tables in Appendix B for the 3- and 4-in. pipe at emitter discharge (q) = 95 gpm:

$$J_{(a,b)} = J_{(a)} - J_{(b)}$$

$$J_{(3,4)} = 1.34 - 0.38 = 0.96\text{ ft/100 ft}$$

Step 6—Plot the points representing the Q_s' used in step 4 and q found in step 5 on log-log graph paper as in figure 7–33. For the 3- and 4-in. PVC pipes in this example, the point is Q_s' = 100 gpm and q = 95 gpm.

Step 7—Draw a line with a slope of −1.80 through each of the points plotted in step 6. These lines represent the set of q values that give the same fixed-plus-operating cost with adjacent sizes of pipe for various Q values. Each pair of lines defines the region in which the pipe size common to both lines is the most economical size to use.

Step 8—Draw a set of vertical lines that represent the q that would give a velocity of 5 ft/s for each pipe size. For the 3-in. pipe this is 132 gpm (see Appendix B), which is represented by the solid vertical line separating regions 3 and 4 of figure 7–33. Since velocity restrictions override economic considerations, the vertical line defines the boundary between the 3- and 4-in. pipe regions at a flow rate of 132 gpm. (The dashed extensions are for velocities of 7 ft/s.)

The economic pipe-selection chart for PVC thermoplastic IPS pipe with minimum acceptable SDR rating (fig. 7–33) is based on pipe cost at $1.00/lb, C_{whp} = $100.00, and CRF = 0.100. The negative-sloping lines represent all the possible Q-vs.-q values for each of the adjacent pairs of pipe sizes that will give the same sum of fixed costs plus operational costs. The zone between adjacent lines defines the region of Q-vs.-q values when the pipe size that is common to both lines is the most economical selection. Figure 7–33 is universally applicable for the most economical selections of pipe size in any sized series system for the economic boundary conditions used. Uses of this chart for manifold and main-line design are presented for drip and spray systems under Sample Design for Trickle Irrigation Systems.

To use figure 7–33 for a system with various economic factors, the total system capacity (Q_s) must be adjusted to compensate for various C_{whp} and CRF values. To do this, first compute the C_{whp} by equation 7–57.

$$C_{whp} = \frac{(Q_t)(P_{uc})[EAE(r)]}{(E_p)(BHP/P_u)} \qquad \textbf{(7–57)}$$

Where

- Q_t = average pump operating time per season, hours, equation 7–37.
- EAE(r) = the equivalent annual cost factor of the rising energy cost, taking into account the time value of money and depreciation of equipment over the life expectancy, table 7–8 or equation 7–55.
- P_{uc} = unit cost of power, dollars per kilowatt-hour.
- E_p = pump efficiency.
- BHP = brake horsepower.
- P_u = unit of power.

Next, determine the system flow-rate adjustment factor (A_f) by equation 7–58.

$$A_f = \frac{0.001C_{whp}}{(CRF)(P_c)} \qquad \textbf{(7–58)}$$

Where

- CRF = capital recovery factor, table 7–8 or equation 7–56.
- P_c = pipe cost, dollars per pound.

The system flow rate for entering the economic chart (Q_s'), gallons per minute, is computed by equation 7–59.

$$Q_s' = A_f Q_s \qquad \textbf{(7–59)}$$

Where

- Q_s = system flow rate under consideration, gallons per minute.

The constant 0.001 in equation 7–58 is the number that gives $A_f = 1$ with the economic factors used in developing figure 7–32. For economic pipe-size selection charts developed from other economic factors, the constant must be changed so that $A_f = 1$ for the C_{whp}, CRF, and pipe cost/unit used.

The procedure using the economic design chart and main-line design strategy as presented under Sample Designs for Trickle Irrigation Systems, Drip System, involves the following:

Step 1—Enter the vertical axis of figure 7–33 with Q_s' and select an "economic pipe size" for the q in each section of main-line pipe. (To hold velocities below 5 ft/s, stay within the solid vertical boundary lines.)

Step 2—Determine the head loss from pipe friction (h_f) in each section of pipe by equation 7–49a or 7–49b or from the pipe friction tables, Appendix B.

Step 3—Compute the pressure head required to overcome pipe friction plus elevation difference between the pump and each manifold inlet at m[$(H_{fe})_m$], feet, by equation 7–60.

$$(H_{fe})_m = \sum_{1}^{m} h_f \pm \triangle El \qquad \textbf{(7–60)}$$

Where

- $\sum_{1}^{m} h_f$ = sum of the pipe friction losses between the pump and manifold inlet at m, feet.
- $\triangle El$ = difference in elevation between the pump and manifold m (+ is uphill

to manfold and − is downhill), feet.

Step 4—Once the $(H_{fe})_m$ has been determined for the critical manifold, the size of other main-line branches can often be reduced. Other prospects for reduction are sections of main line that connect points that are downstream and have lower elevations than the critical manifold. The exact length of the smaller diameter pipe that will increase the head loss between two points by a specified amount (L_s), feet, can be computed by equation 7–61.

$$L_s = \frac{\triangle H}{J_s - J_l} \times 100 \qquad \textbf{(7–61)}$$

Where

$\triangle H$ = desired pressure-head increase between two points, feet.
J_s = head loss gradient of the smaller pipe, feet per 100 feet.
J_l = head loss gradient of the larger pipe, feet per 100 feet.

Lateral Line Design

This section presents the procedures for determining lateral characteristics such as: (1) flow rate and inlet pressure, (2) location and spacing of the manifolds that in effect set the lateral lengths, and (3) estimated differences in pressure within laterals.

On fields where the average slope along the laterals is less than 3 percent, it is usually most economical to supply laterals to both sides of each manifold. The manifold should be positioned so that, starting from a common manifold connection, the minimum pressures in the pair of laterals (one to either side of the manifold) are equal. Thus, on level ground the pair of laterals should have equal lengths (l) and the manifold spacing (S_m) = 2l = L.

If the ground slopes along the laterals (rows), the manifold should be shifted uphill from the center line. The effect is to shorten the upslope lateral and lengthen the downslope lateral so that the combination of pipe friction loss and elevation difference is in balance. The amount of the shift can be determined either graphically or numerically.

The spacing of manifolds is a compromise between field geometry and lateral hydraulics. As practical limits for preliminary design purposes, lateral pressure-head differences ($\triangle h$) can be limited to one-half of the allowable subunit pressure-head variations ($0.5\ \triangle H_s$) where the manifold plus attached laterals make up a subunit. The $\triangle h$ for a given S_m and set of lateral specifications is about the same for laterals on level fields as for laterals with slopes of as much as 2 percent. This observation helps in computing the S_m and in designing the layout of the pipeline network. For simplification, the design procedure is based on laterals that have an average emitter flow rate (q_a).

Characteristics

Several general characteristics of laterals are important to the designer.

Length.—When two laterals extend in opposite directions from a common inlet point on a manifold, they are referred to as a *pair of laterals.* For example, the laterals in figure 7–27 are paired. The length of a pair of laterals (L) is equal to the manifold spacing (S_m). The length of a *single lateral* that extends in only one direction from a manifold is designated by l.

Flow rate.—The flow rate of a lateral (q_l), gallons per minute, can be computed by equation 7–62.

$$q_l = \frac{l}{S_e}\frac{q_a}{60} = \frac{n_e q_a}{60} \qquad \textbf{(7–62)}$$

Where

S_e = spacing of emitters on the lateral, feet.
n_e = number of emitters along the lateral.
q_a = average emitter flow rate, gallons per hour.

Inlet pressure.—Sometimes it is useful to know the inlet pressure required by the average lateral in a system. The average emitter pressure head (h_a) is computed as the head that will give q_a. The general location of the average emitter that yields q_a at h_a is between x/L = 0.60 and x/L = 0.62 for constant-diameter laterals. Furthermore, about three-fourths of the head loss occurs between the average emitter and the inlet, where the flow is greatest. As flow in the lateral decreases because of water being discharged through the emitters, the head loss curve flattens (see fig. 7–31) so that only about one-fourth of the total loss takes place between the average emitters and the end.

Data in table 7–7 demonstrate the above as follows:

1. The average value of 100 h_{fx}/L is 2.67 when end effects and the values at $x/L = 0.05$ and 0.15 (which are not included in table 7–7) are accounted for.

2. The location of 100 $h_{fx}/L = 2.67$ can be determined by letting the friction gradient (J F) = 10.00 (which is the value used in generating table 7–7) and solving to obtain:

$$\frac{x}{L} = \left(\frac{2.67}{10.00}\right)^{1/2.75} = 0.62$$

3. The portion of the total friction loss between $x/L = 0.62$ and the closed end is 2.67/10.00 or about one-fourth.

The inlet pressure head that will give h_a (h_l), feet, for a pair of constant-diameter laterals with $L = S_m$ laid on a uniform slope can be computed by equations 7–63a and 7–63b.

$$h_l = h_a + 0.75h_{fp}[z^{3.75} + (1 - z)^{3.75}] - \frac{\triangle El}{2}(2z - 1) \qquad \textbf{(7–63a)}$$

Where

h_{fp} = friction loss in a lateral with length L, feet.
z = location of the inlet to the pair of laterals that gives equal minimum pressures in both uphill and downhill members (expressed as the ratio of the length of the downhill lateral to L.)
$\triangle El$ = absolute difference in elevation between the two ends of the pair of laterals, feet.

For level fields this reduces to:

$$h_l = h_a + 0.75h_{fp}(0.5)^{2.75} = h_a + 0.11h_{fp} \qquad \textbf{(7–63b)}$$

For a single constant-diameter lateral laid on uniform slopes, h_l can be computed by equation 7–63c,

$$h_l = h_a + \frac{3h_f}{4} + \frac{\triangle El}{2} \qquad \textbf{(7–63c)}$$

and the pressure head at the closed end of the lateral (h_c), feet, can be computed by equation 7–64a or 7–64b.

$$h_c = h_a - \left(\frac{h_f}{4} + \frac{\triangle El}{2}\right) \qquad \textbf{(7–64a)}$$

$$h_c = h_l - (h_f + \triangle El) \qquad \textbf{(7–64b)}$$

Where

h_f = head loss from pipe friction, feet.
$\triangle El$ = change in elevation (+ for laterals running uphill from the inlet and − for laterals running downhill, feet).

Tapered laterals.—Usually, constant-diameter laterals are used, because they are convenient to install and maintain, but tapered laterals may be less expensive. Tapered laterals are sometimes used on steep slopes where the increase in pressure from the slope would result in too much pressure at the end.

If a lateral were tapered so that the friction loss per unit length were uniform throughout, the average pressure would occur at the midpoint. In such a lateral, the term $3h_f/4$ in equation 7–63c would be changed to $h_f/2$. It is impractical to use more than two pipe sizes; therefore, when calculating h_l for a tapered lateral, replace $3h_f/4$ with $2h_f/3$ in equation 7–63c. When computing h_c by equation 7–64a, replace $h_f/4$ with $h_f/3$.

For tapered laterals, h_f must be computed in a three-step process:

Step 1—Compute h_f by equation 7–52 for the full length of the lateral that has the larger diameter pipe.

Step 2—Compute h_f values for both the large- and the small-diameter pipes for a lateral length equal to the length of small-diameter pipe and determine the difference between these values.

Step 3—The h_f for the tapered lateral will equal the h_f found in step 1 plus the difference in the two h_f values found in step 2.

In computing h_f for tapered laterals, all the computations involving equation 7–52 (and those using monographs or slide rule calculators) must include the closed end of the lateral or manifold. This must be done because use of the reduction coefficient (F) involves the assumption that (1) the discharges from all outlets are equal, and (2) no water flows beyond the last outlet of the pipe section being considered. For further details on design of multioutlet pipeline, refer to Manifold Design.

Spacing of Manifolds

The manifold spacing (S_m) in orchards should be such that adjacent manifolds are a whole number of tree spacings (S_p) apart. Furthermore, it is most convenient to have the same S_m throughout the field in all crops. A detailed example is presented under Drip System in Sample Designs for Trickle Irrigation Systems. The procedure is as follows:

Step 1—Inspect the field layout and select a reasonable S_m in accordance with the criteria listed above.

Step 2—Determine the lateral pipe friction loss (h_f) with laterals half as long as S_m (eq. 7–51 and 7–52).

Step 3—Assume that h_f = the pressure head difference along the lateral ($\triangle h$), i.e., the field is level, and compare the latter with 0.5 times the allowable subunit pressure-head variation ($\triangle H_s$) (eq. 7–34). If $\triangle h$ is much larger than 0.5 $\triangle H_s$, S_m should be decreased. If it is much smaller, S_m may be increased.

Once the friction loss for a given length of lateral has been computed, the friction loss for any other length of lateral can be computed by equation 7–65a, which is a rearrangement of equation 7–53.

$$(h_f)_b \cong (h_f)_a\left(\frac{l_b}{l_a}\right)^{2.75} \qquad \textbf{(7–65a)}$$

Where

l_a and l_b	=	original and new lateral pipe length, feet.
$(h_f)_a$ and $(h_f)_b$	=	original and new lateral pipe friction losses, feet.

Conversely, the length of lateral (l_b) that will give any desired $(h_f)_b$ can be computed by equation 7–65b.

$$l_b \cong l_a\left(\frac{(h_f)_b}{(h_f)_a}\right)^{1/2.75} \qquad \textbf{(7–65b)}$$

Location of Manifolds

As discussed earlier, on level fields laterals should extend an equal length (l) to either side of the manifolds so that l = half the manifold spacing (S_m/2). On sloped fields the manifolds should be shifted uphill from the center line of the subunits, as shown in figure 7–9. The location of the manifold that will give the same minimum and maximum pressures in the uphill and downhill laterals can be determined either graphically or numerically.

Graphical solution.—The graphical solution is based on the general friction curve, figure 7–31. A detailed example of the graphical determination is presented under Drip System in Sample Designs for Trickle Irrigation Systems. The procedure is as follows:

Step 1—Determine the equivalent head-loss gradient (J′), feet, and reduction coefficient to compensate for the discharge (F) for a single lateral equal in length to the S_m. (Note: this lateral will have twice the flow rate used in step 2 of the manifold-spacing procedure.)

Step 2—Place an overlay on figure 7–31 and trace the friction curve and horizontal boundaries. For use of the 0-to-10 dimensionless horizontal scale, values for specific problems must be multipled by 10/J′F, found in step 1.

Step 3—On the overlay, draw a line representing the ground surface such that (a) the line is tangent to the friction curve and (b) the drop in elevation or slope is properly scaled.

Step 4—Locate the best manifold positions by moving the overlay down until the dashed friction curve coincides with the ground line at manifold position (x/L) = 1.0. The dashed curve represents the uphill lateral, and the intersection between the two curves is the optimum manifold location for the given S_m and topography. (Note that the solid and dashed curves intersect at x/L = 0.5 on figure 7–31. This is obviously the optimum manifold location for a level field. The dashed curve is a mirror image of the x/L = 0 to 0.5 position of the solid friction curve.)

Step 5—Adjust the manifold location uphill by as much as 3/4 of the tree spacing (S_p) or downhill by as much as 1/4 S_p, so that it falls midway between tree spacings.

Step 6—Determine the maximum head variation along the pair of laterals ($\triangle h$), feet, by first determining the maximum distance the friction curves are above the ground surface line (which is equivalent to the scaled value of $\triangle h$ divided by L/100) and then determining $\triangle h$ by equation 7–66.

$$\triangle h = \frac{J'F}{10}\,\frac{L}{100}\left(\frac{\triangle h}{L/100}\right)' \qquad \textbf{(7–66)}$$

Where

L = S_m, feet.
$(100\triangle h/L)'$ = maximum scalar distance between the friction curve and the ground surface line in the graphical solution.

Numerical solution.—The numerical solution, based on equation 7–53 and presented under Drip System in Sample Designs for Trickle Irrigation Systems, follows the same logic and procedural steps as the graphical solution. Figure 7–34 shows the dimensionless terms used in the computation that follows.

Step 1—Determine J′ and F for a single lateral equal in length to S_m.

Step 2—Find the tangent location (Y) by equation 7–67 when the average slope of the ground line (S), percent, ≤ J′; when S > J′, Y = 1. This is the x/L where the friction curve is tangent to the ground, figure 7–34.

$$Y = (S/J')^{1/1.75} \qquad \textbf{(7–67)}$$

Step 3—Solve for the **unusable slope component** (S′) by equation 7–68. This is the amount the

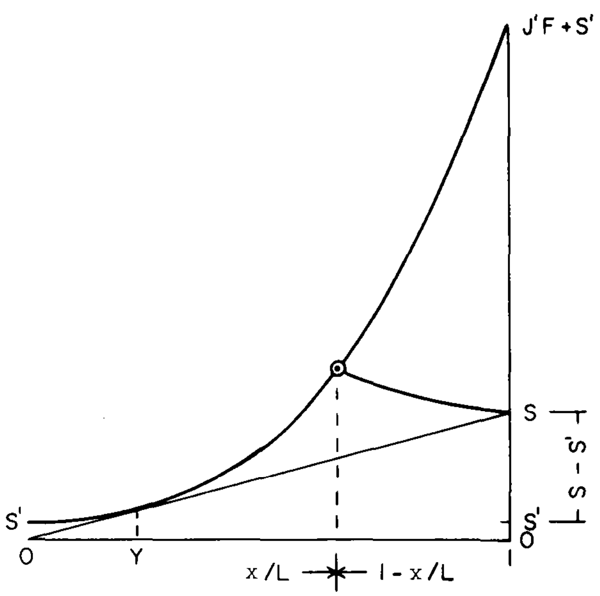

Figure 7–34.—Dimensionless sketch showing terms used in numerical solution of optimum position for manifold. J′F = friction gradient; S′ = average slope of the ground line; Y = tangent location; x/L = manifold position.

friction curve needs to be raised so that it does not dip below the ground line.

$$S' = SY - J'F(Y)^{2.75} \qquad \textbf{(7–68)}$$

Step 4—Determine the optimum x/L that satisfies equation 7–69.

$$\frac{S - S'}{J'F} = (x/L)^{2.75} - (1 - x/L)^{2.75} \qquad \textbf{(7–69)}$$

To satisfy the equation, first determine the quantity on the left, and then by trial and error find the appropriate x/L value that will satisfy it.

Step 5—Adjust the manifold to fall midway between two tree rows as in step 5 of the graphical solution.

Step 6—For laterals on relatively mild slopes, the maximum △h along the pair of laterals can be determined from the x/L value that represents the actual manifold location selected by equation 7–70.

$$\triangle h = \frac{L}{100}[J'F(x/L)^{2.75} + S' - S(x/L)] \qquad \textbf{(7–70)}$$

For steep slopes the maximum △h may occur at the closed end of the downstream lateral. To check for this possibility, determine the difference ($\triangle h_c$) between the downstream-end and minimum pressure heads by equation 7–71a or directly by equation 7–71b.

$$\triangle h_c = S'(L/100) \qquad \textbf{(7–71a)}$$

$$\triangle h_c = S^{1.57}(J')^{-0.57}(1 - F)L/100 \qquad \textbf{(7–71b)}$$

Pressure Difference

The pressure head difference (△h) along the laterals must be known for estimating the final emission uniformity (EU) of the system. As mentioned earlier, △h should be about 0.5 times the allowable subunit pressure-head variation ($\triangle H_s$) or less. Methods for computing △h are stated in step 6 of both the graphical and numerical solutions for manifold positioning (see above). However, for some designs the manifold placement is dictated by other considerations and △h must be determined by some other means.

For laterals on downhill slopes of less than 0.3

percent, level ground, or uphill slopes, $\triangle h$ can be assumed equal to the lateral inlet pressure head (h_l) minus the pressure head at the closed end (h_c) and equation 7–63 and 7–64 can be used to determine h_l and h_c. For steeper downhill laterals, equations 7–63 and 7–64 still are valid as long as the slope is fairly uniform. However, a different procedure must be used to estimate $\triangle h$ because the highest and lowest pressures will no longer be at h_l and h_c. This is apparent in figure 7–34 where the pressure is lowest at the manifold position (x/L) = the tangent location (Y).

Use the following steps to compute $\triangle h$ for laterals on slopes steeper than 3 percent.

Step 1 through 3—Follow steps 1 through 3 of the numerical solution above for determining the position for the manifold on sloping fields, except that the equivalent head loss gradient (J′) and the reduction coefficient to compensate for the discharge (F) should be determined for the length of lateral under study rather than for the manifold spacing (S_m).

Step 4—For relatively mild slopes the maximum difference in pressure head ($\triangle h$) along the lateral can be computed by equation 7–72.

$$\triangle h = \frac{L}{100}(J'F + S' - S) \qquad \textbf{(7–72)}$$

Where

J′F	=	friction gradient found in step 1.
S′	=	unusable slope component.
S	=	average slope of the ground line, percent.

Equation 7–72 is the same as equation 7–71 with x/L = 1 because the manifold would be located at x/L = 1 in figure 7–34.

For steep slopes the maximum difference may occur at the closed end. To test for this possibility, determine the difference between the downstream and minimum pressure heads ($\triangle h_c$) by equation 7–71 or equation 7–71b.

Manifold Design

This section presents the procedures for determining the characteristics of a manifold, flow rate, pipe sizes to keep within the desired pressure-head differential, and inlet pressure needed to give the desired average emitter discharge (q_a).

On fields where the average slope along the manifolds is less than 3 percent, it is usually more economical to install manifolds both uphill and downhill from the main line. The inlet from the main line should be positioned so that starting from a common main line connection the minimum pressures along the pair of manifolds (one to either side of the manifold) are equal. Thus on level ground the pair of manifolds should have equal lengths.

Where the ground slopes along the manifolds (across the rows), the manifold inlet should be shifted uphill from the center. The effect is to shorten the uphill manifold and lengthen the downhill manifold so the combination of friction losses and elevation differences are in balance. This can be done with the aid of a selection graph for tapered manifolds and either graphically or numerically for single-pipe-size manifolds. The numerical procedure is similar to that described for positioning lateral inlets.

The main line layout is a compromise between field geometry and manifold hydraulics. The allowable manifold pressure-head variation may be computed by equation 7–73.

$$(\triangle H_m)_a = \triangle H_s - \triangle h' \qquad \textbf{(7–73)}$$

Where

$\triangle H_s$	=	the allowable subunit pressure variation, feet.
$\triangle h'$	=	the greater of $\triangle h$ or $\triangle h_c$, the lateral-line pressure variation, feet.

For simplification, the design procedure is based on laterals with the average emitter flow rate (q_a). Thus, for manifolds serving rectangular subunits, the lateral flow rate (q_l) is assumed to be constant.

Characteristics

Manifolds are usually tapered and designed to use pipe of two, three, or four sizes. For adequate flushing, the diameter of the smallest pipe should be no less than one-half that of the largest pipe. The velocity should be limited to about 7 ft/s in manifolds. (This is higher than the 5 ft/s used for main lines because the outlets along the manifold are always open, so water-hammer shock is dampened.)

Length.—When two manifolds extend in opposite directions from a common inlet point, they are referred to as a pair of manifolds. For example, the manifolds serving blocks I and II in figure 7–27 are a pair. If only one manifold is connected at an inlet point, as in figure 7–9, the design is termed a single-manifold configuration.

The length of a pair of manifolds (L_p) can be computed by equation 7–74.

$$L_p = [(n_r)_p - 1]S_r \qquad \textbf{(7–74)}$$

Where

$(n_r)_p$ = number of row (or lateral) spacings served from a common inlet point.
S_r = row spacing, feet.

The length of a single manifold (L_m), feet, is usually equal to that computed by equation 7–75.

$$L_m = (n_r - 1/2)S_r \qquad \textbf{(7–75)}$$

Where

n_r = number of row (or lateral) spacings served by the manifold.
S_r = row spacing, feet.

Inlet position.—For optimal hydraulic design, the inlet to pairs of manifolds should be located so that the minimum pressure in the uphill manifold equals that in the downhill manifold. However, field boundaries, roadways, topographic features such as drains, structures, or existing facilities often dictate the location of main lines and manifold inlets. Furthermore, sometimes the inlet must be positioned to balance system flow rates where manifolds making up pairs are operated individually.

Obviously, for single manifolds the inlet location is fixed. Where a pair of manifolds lies on a contour, the inlet should be in the center of the pair. For pairs of manifolds of a single pipe size serving rectangular subunits, the procedure for locating the inlet is essentially the same as that described for locating lateral-line inlets. To use either the graphical or numerical procedure outlined under Lateral Line Design, replace S_m with L_p and select a suitable pipe size so that the head loss for a manifold with $L_m = L_p/2$ is less than the allowable manifold pressure variation $[(\triangle H_m)_a]$, feet.

The inlet location that will balance the minimum uphill and downhill pressures is not precise for tapered manifolds because it depends on the selection of pipe sizes and lengths. Figure 7–35 was developed as a guide to selecting the inlet location for tapered manifolds. The figure's use greatly simplifies the selection process. For example, if the manifold is on the contour, the average slope of the ground line (S), percent, = 0; therefore, the slope ratio is 0 and the distance from the downhill end (x) = 0.5 L_p, which is the center of the pair of manifolds.

Assuming that $(\triangle H_m)_a$ = 0.5 ft for a pair of manifolds with L_p = 1,000 ft and S = 1 percent, the manifold inlet location can be found as follows: slope ratio = 2; x ≅ 0.75 L_p from figure 7–35; therefore, L_m = 750 ft for the downhill manifold and L_m = 250 ft for the uphill manifold.

Proper location of the inlet to pairs of sloping manifolds can increase both uniformity and savings of pipe costs. The pipe cost savings result from replacing the larger diameter pipe at the inlet end of the long downhill manifold with the smaller diameter pipe used for the short uphill manifold.

Inlet pressure.—As a rule, the main pressure-control (adjustment) points are at the manifold inlets. Therefore, the manifold inlet pressure must be known to properly manage the system and determine the total dynamic head required. The manifold

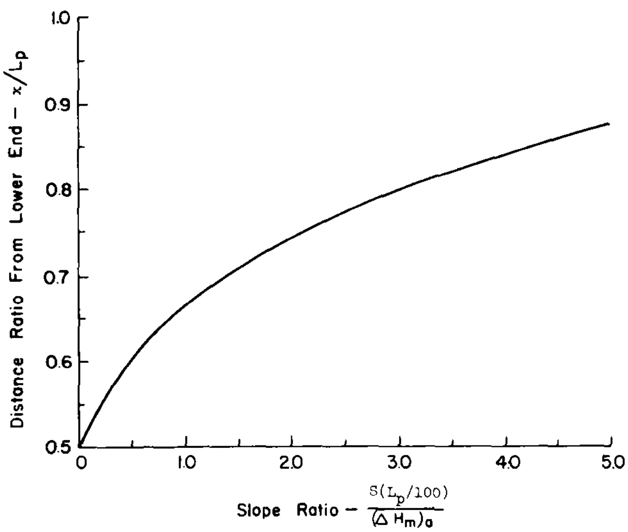

Figure 7–35.—Graph for selecting location of inlet to a pair of tapered manifolds on a slope. x = distance of inlet from closed end; L_p = length of the pair of manifolds; S = average slope of the ground line; $(\triangle H_m)_a$ = allowable manifold pressure variation.

inlet pressure head (H_m), feet, for subunits with single pipe-size laterals can be computed by equations 7–76a and 7–76b.

$$H_m = h_l + \triangle H'_m \qquad \textbf{(7–76a)}$$

Where

h_l = lateral inlet pressure that will give the average pressure head (h_a), feet. For laterals with one tubing diameter on uniform slopes, h_l can be determined either by equation 7–63 or graphically.

$\triangle H'_m$ = difference between the manifold *inlet* pressure and h_l, feet. It can be estimated by:

$$\triangle H'_m = MH_f + 0.5 \triangle El$$

in which M = 0.75 for manifolds with one pipe size, M = 0.6 for manifolds with two pipe sizes, and M = 0.5 for manifolds with three or more pipe sizes. It can also be estimated graphically.

For tapered laterals:

$$H_m = h_a + \triangle h' + \triangle H'_m \qquad \textbf{(7–76b)}$$

Where

$\triangle h'$ = difference between the lateral inlet pressure and h_a, feet. For tapered laterals $\triangle h'$ should be estimated graphically.

Economic-Chart Design Method

An economic pipe-size selection chart such as figure 7–33 can be used to select pipe sizes and lengths for manifolds serving rectangular subunits. The chart used for a design should be specifically constructed for the pipe materials and wall thicknesses (or pressure ratings) that the design calls for. (Figure 7–33 is designed for PVC thermoplastic IPS pipe with the minimum SDR ratings.) The general procedure for using the economic chart is presented in Pipeline **Hydraulics**.

The procedure for the economic chart method for designing tapered manifolds is as follows:

Step 1—Compute the annual cost per water horsepower (C_{whp}) by equation 7–57.

Step 2—Determine the system flow-rate adjustment factor (A_f) by equation 7–58.

Step 3—Calculate the adjusted system flow (Q'_s) for entering the chart, gallons per minute, by equation 7–77.

$$Q'_s = A_f q_m \qquad \textbf{(7–77)}$$

Where

q_m = flow rate in the manifold, gallons per minute. (This is equal to the number of laterals served by the manifold times the flow rate per lateral. For a pair of manifolds use the flow rate in the downhill [larger] manifold.)

Step 4—Enter the vertical axis of figure 7–34 with Q'_s, draw a horizontal line across the graph, and record the flow rates (along the bottom axis) where this line intersects the upper limit of each pipe-size region. These are the flow rates at which each subsequently larger pipe diameter should be used. Select no more than four pipe sizes so that the smallest pipe is no less than half the diameter of the largest pipe.

Step 5—Calculate the lengths of each size pipe by equation 7–78.

$$L_d = \frac{q_d - q_{d-1}}{q_m} L_m \qquad \textbf{(7–78)}$$

Where

L_d = length of pipe with diameter d, feet.

q_d = upper-limit flow rate for the pipe with diameter d, gallons per minute.

q_{d-1} = upper-limit flow rate for the pipe with the next smaller diameter, gallons per minute.

L_m = length of the manifold used in computing q_m, feet.

Step 6a—Determine the pressure head loss from pipe friction (H_f) in the tapered manifold. The general theory for doing this is outlined in the Lateral Line Design section. A detailed example of the numerical process is presented under Drip System in Sample Designs for Trickle Irrigation Systems.

Step 6b—Figures 7–36 and 7–37 were prepared to provide a graphical solution that greatly simplifies the calculation of the head loss in a tapered manifold. The figures are plots of the head loss curves for manifolds made up of PVC thermoplastic IPS pipe with different nominal diameters with the minimum SDR ratings. Figure 7–36 is based on manifolds with 2-gpm outlets every 20 ft and figure 7–37 is based on manifolds with 6-gpm outlets every 60 ft. Use figure 7–36 for manifold outlet discharges below 3.4 gpm and figure 7–37 for discharges between 3.4 and 10.2 gpm. (Note that when a manifold feeds pairs of laterals, the outlet discharges are equal to the average discharge to each pair of laterals.)

The H_f values given in figures 7–36 and 7–37 are both based on 0.1 gpm/ft. The H_f values obtained from the figures must be multiplied by a scale factor (k) to reflect the actual manifold discharge per unit length. The dimensionless k can be computed by equations 7–79a and 7–79b.

$$k = (L_m/q_m)(0.1 \text{ gpm/ft}) \tag{7–79a}$$

$$k = (S_l/q_l)(0.1 \text{ gpm/ft}) \tag{7–79b}$$

Where

S_l = lateral spacing, feet.
q_l = lateral flow rate, gallons per minute.

To use the graphical method for determining the head loss from pipe friction:

Step 1—Lay a piece of tracing paper on figure 7–36 or 7–37 (depending on q_l) and draw lines through the origin along the abscissa and ordinate.

Step 2—Draw vertical lines at flow rates representing the divisions between successive pipe sizes obtained in step 4.

Step 3—Trace the curve representing the smallest diameter pipe between the origin and the flow rate at which the next largest diameter pipe should begin.

Step 4—Slide the overlay down so that the upper end of this curve (for the smaller pipe) coincides with the curve for the (next) larger pipe at the flow rate where pipe size should change and trace the curve to the next pipe-size change point.

Step 5—Repeat step 4 until the traced set of curve segments reaches q_m.

Step 6—The series of head loss segments represents the head loss in the tapered manifold; and the sum of the head losses in each segment is proportionate to H_f at q_m on the overlay. The actual H_f can be computed by equation 7–80.

$$H_f = k(H_{fg}) \tag{7–80}$$

Where

H_f = actual pressure-head loss in the manifold from pipe friction, feet.
(H_f) = pressure-head loss in the manifold from pipe friction, taken from graph overlay in above steps, feet.

An example of the graphical solution is presented in figure 7–42 under Manifold Design, Drip System, in Sample Designs for Trickle Irrigation Systems.

Step 7—Estimate manifold pressure-head variation ($\triangle H_m$) for the tapered manifolds by equations 7–81a, 7–81b, and 7–81c. For level manifolds:

$$\triangle H_m = H_f \tag{7–81a}$$

For uphill manifolds:

$$\triangle H_m = H_f + S(L_m/100) \tag{7–81b}$$

For downhill manifolds $\triangle H_m$ can be determined graphically, or when $\triangle El < H_f$, it can be approximated by:

$$\triangle H_m = H_f - [S(0.1 - \frac{0.36}{c})\frac{L_m}{100}] \tag{7–81c}$$

Where

S = slope of the manifold, percent.
c = number of pipe sizes used in the manifold.

Step 8—If $\triangle H_m \leq 1.1$ times the allowable manifold pressure variation $(\triangle H_m)_a$, feet, the design is satisfactory. If $\triangle H_m > 1.1(\triangle H_m)_a$, the manifold pipe sizes must be adjusted to reduce H_f. Small adjustments can usually be made by inspection. For large adjustments calculate a modified system flow rate (Q_s'') by equations 7–82a, 7–82b,

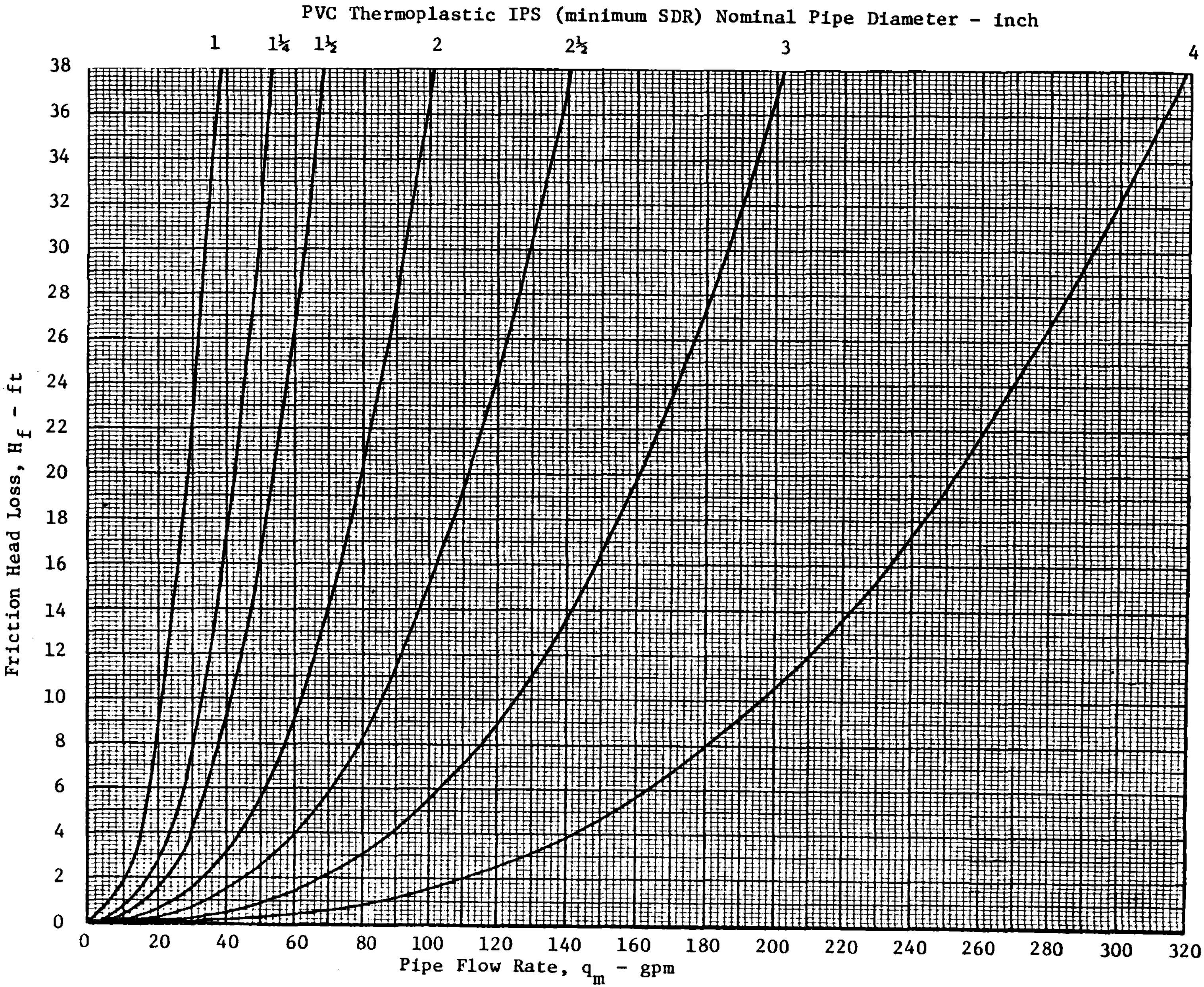

Figure 7-36.—Standard manifold friction curves for 2-gpm outlet every 20 ft.

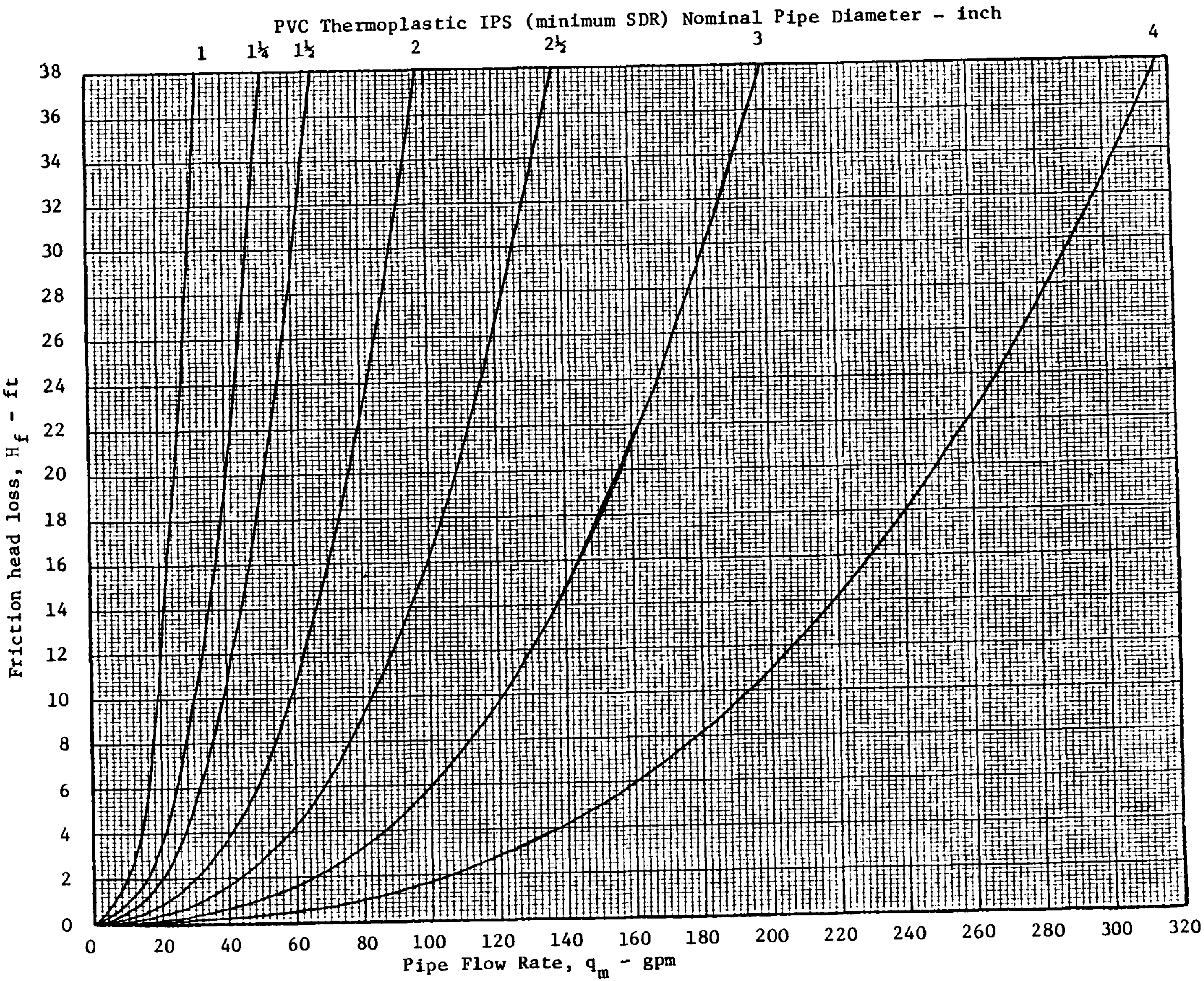

Figure 7-37.—Standard manifold friction curves for 6-gpm outlet every 60 ft.

and 7–82c for reentering the economic pipe-size selection chart. For level manifolds:

$$Q_s'' = \frac{H_f}{(\triangle H_m)_a} Q_s' \qquad \textbf{(7–82a)}$$

For uphill manifolds:

$$Q_s'' = \frac{H_f}{(\triangle H_m)_a - S(L_m/100)} \qquad \textbf{(7–82b)}$$

And for downhill manifolds:

$$Q_s'' = \frac{H_f}{(\triangle H_m)_a + [S(1.0 - \frac{0.36}{c})L_m/100]} \qquad \textbf{(7–82c)}$$

Step 9—Repeat steps 4 through 8, beginning with Q_s'', until $(\triangle H_m)_a$ is satisfactory, as specified in step 8.

Step 10—For pairs of manifolds that operate simultaneously from the same regulating value, compute H_m, using the weighted (by length) uphill and downhill values for the amount $(\triangle H_m')$ the manifold inlet pressure differs from lateral line inlet pressure, by equation 7–77a or 7–77b.

General Graphical-Design Method

The graphical-design procedure for manifolds of a single pipe size is the same as that given under Lateral Line Design. The general graphical-design method that follows can be used for tapered manifolds that serve either rectangular or nonrectangular trapezoidal subunits. It is more time consuming than the economic-chart method (which can be used only for rectangular subunits), but it is more precise. A simpler graphical method can, however, be used on rectangular subunits. The alternate graphical method is designed to use the standard manifold curves (figs. 7–36 and 7–37).

The general graphical-design procedure for tapered manifolds (or laterals) is the same for both rectangular and nonrectangular trapezoidal subunits. However, the reduction coefficient to compensate for the discharge (F) used to compute friction loss in multiple-outlet pipelines and the ratios for plotting the dimensionless pipe-friction loss curves must be adjusted for the subunit shape. The shape factor of the subunit (S_f) is defined by equation 7–83.

$$S_f = \frac{(q_l)_c}{(q_l)_a} = \frac{(n_p)_c}{(n_p)_a} \qquad \textbf{(7–83)}$$

Where

$(q_l)_c$ = flow rate into the lateral (pair) at the closed end of the manifold, gallons per minute.
$(q_l)_a$ = average lateral (pair) flow rate along the manifold, gallons per minute.
$(n_p)_c$ = number of plants in the row at the closed end of the manifold.
$(n_p)_a$ = number of plants in the average row in the subunit.

The pressure head loss from pipe friction in a manifold (H_f), feet, can be computed by equation 7–84.

$$H_f = JFF_s(L_m/100) = JF'(L_m/100) \qquad \textbf{(7–84)}$$

Where

J = head loss gradient of a pipe, feet per 100 feet.
F_s = manifold pipe-friction adjustment factor, figure 7–37.
JF' = scalar ratio for field shape.
L_m = actual length of the manifold, feet.

The general graphical method for designing tapered manifolds is as follows:

Step 1—Determine the largest pipe size to be used in the manifold. This will be the smallest pipe that will give a manifold pressure-head variation $(\triangle H_m)$ < the allowable manifold pressure variation $[(\triangle H_m)_a]$ by equation 7-81 or possibly one pipe size larger.

To do this:

1. First compute S_f by equation 7–83.
2. Then find F_s for S_f in figure 7–38.
3. Find the value of J in Appendix B.
4. Find F in table 7–6.
5. Compute H_f by equation 7–84.
6. Use H_f in equation 7–81a, 7–81b, or 7–81c to find $\triangle H_m$.

Step 2—Determine four scalar ratios for field shape (JF') values for manifold flow rate (q_m), gallons per minute, using the largest and three next smaller pipe sizes. (The diameter of the mani-

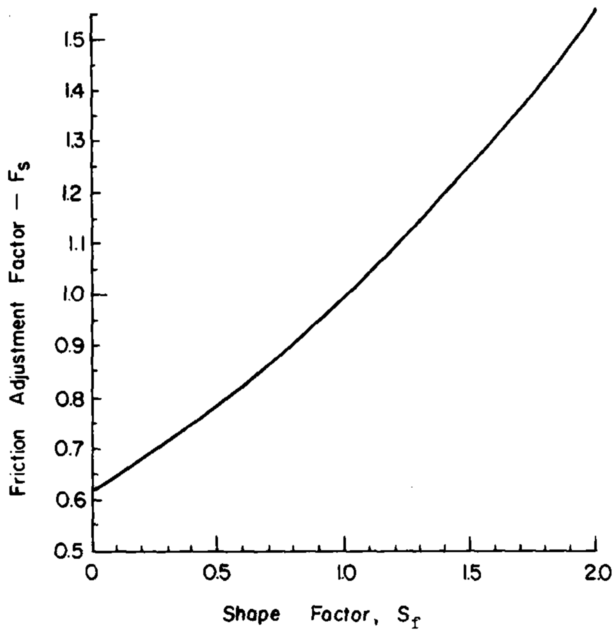

Figure 7–38.—Graph for determining manifold pipe-friction adjustment factors for trapezoidal subunits.

fold's smallest pipe should be at least half the diameter of the manifold's largest pipe.)

If the range of flow rates given by the appropriate table in Appendix B does not include the required q_m, select from the table the value of the head loss gradient of the manifold pipe (J), feet per 100 feet, as J_x for the largest flow rate (q_x) given for the required pipe size. The required J value can then be computed by equation 7–85.

$$J = J_x\left(\frac{q_m}{q_x}\right)^{1.8} \qquad (7\text{–}85)$$

Where

J_x = J value from Appendix B for the largest flow rate in the table for the required pipe size, feet per 100 feet.

q_x = largest flow rate (Q) in the appropriate table for pipe size in Appendix B, gallons per minute.

Step 3—Set up a table to organize the dimensionless data for plotting a set of curves scaled to represent each of the four sizes of pipe. (See table 7–9.) First select the proper values for JF′

Table 7–9.—Scaled values of $\triangle H_m/(L/100)$ for constructing a set of dimensionless manifold friction-loss curves for manifold flow rate (q_m) = 178 gpm and reduction coefficient to compensate for discharge (F) = 0.38

		$\triangle H_m/(L/100)$ at indicated pipe size (in.) and JF′)			
x/L[1]	JF′[2] ratio	2 11.09	2½ 4.41	3 1.59	4 0.42
0.10	0.002	0.02	0.01	0.003	0
0.20	0.013	0.14	0.06	0.02	0.005
0.25	0.023	0.26	0.10	0.04	0.01
0.30	0.037	0.41	0.16	0.06	0.02
0.35	0.057	0.63	0.25	0.09	0.02
0.40	0.081	0.90	0.36	0.13	0.03
0.45	0.112	1.24	0.49	0.18	0.05
0.50	0.149	Velocity	0.66	0.24	0.06
0.55	0.193	limit	0.85	0.31	0.08
0.60	0.245		1.08	0.39	0.10
0.65	0.305		1.35	0.48	0.13
0.70	0.374		Velocity	0.59	0.16
0.75	0.452		limit	0.72	0.19
0.80	0.540			0.86	0.23
0.85	0.638			1.01	0.27
0.90	0.747			1.19	0.31
0.95	0.868			1.38	0.36
1.00	1.000			1.59	0.42

[1]It is normally sufficient to use only the 0.1, 0.2, 0.3, . . . 1.0 values of x/L.
[2]Note that scalar ratios (JF′) from table 7–10 were divided by 10.

ratio vs. x/L for the nearest S_f from table 7–10.

Then multiply the JF′ values found in step 2 for each of the four pipe sizes by each of the JF′ ratios from the table. There is, however, no need to compute values representing velocities greater than 7 ft/s. Furthermore, the full 0.1, 0.2. . . values should give enough data points.

Step 4—Plot the data tabulated in step 3 on regular graph paper with (x/L) as the abscissa and $\triangle H_m/(L/100)$ as the ordinate (see figure 7–39). This set of curves represents a set of four single-size pipe manifolds drawn to a single dimensionless scale.

Step 5—Determine the dimensionless allowable head-loss ratio (j) by equation 7–86.

$$j = \frac{(\triangle H_m)_a}{L_m/100} \qquad \textbf{(7–86)}$$

This represents the allowable pipe-friction loss following the same proportional scale as the set of pipe friction curves.

Step 6—Place a transparent overlay on the set of dimensionless pipe-friction curves, then trace the horizontal and vertical scales and the left vertical boundary (see figure 7–40).

Step 7a—For level manifolds draw a sloping line through the origin and through j at x/L = 1. Then draw a second sloping line parallel to the first and passing through 0.9j at x/L = 1. (See the solid and dashed lines in figure 7–40.)

Step 7b—For steeply (down) sloping manifolds (or pairs of manifolds) where S > 3j, draw a sloping line from the origin to S = △El/100L at x/L = 1. (This line represents the ground slope drawn to the same scale as the friction curves.) Then draw a second line above and parallel to the ground slope line and passing through (j + S) at x/L = 1. (See the solid and dashed lines in figure 7–41).

Step 7c—For mildly (down) sloping manifolds (or pairs of manifolds) where S < 3j, draw a sloping line from 0.15S at x/L = 0 to (j + S) at x/L = 1. Then draw a second line below and parallel to the first and passing through 0.9(j + S) at x/L = 1.

Table 7–10.—Scalar JF′ ratios for constructing dimensionless curves of x/L vs. $\triangle H_m/(L/100)$ for various field-shape factors (S_f)[1]

	JF′ ratio for indicated S_f				
x/L	0.0	0.5	S_f = 1.0	1.5	2.0
0.10	0.00	0.01	0.02	0.03	0.05
0.20	0.01	0.06	0.13	0.19	0.25
0.25	0.02	0.11	0.23	0.34	0.44
0.30	0.04	0.20	0.37	0.54	0.69
0.35	0.08	0.31	0.57	0.80	1.00
0.40	0.15	0.47	0.81	1.12	1.38
0.45	0.26	0.68	1.12	1.50	1.83
0.50	0.42	0.96	1.49	1.95	2.34
0.55	0.64	1.30	1.93	2.47	2.91
0.60	0.96	1.73	2.45	3.05	3.55
0.65	1.38	2.26	3.05	3.70	4.23
0.70	1.94	2.90	3.74	4.42	4.97
0.75	2.66	3.66	4.52	5.20	5.74
0.80	3.58	4.57	5.40	6.05	6.56
0.85	4.73	5.46	6.38	6.95	7.39
0.90	6.16	6.89	7.47	7.92	8.25
0.95	7.90	8.33	8.68	8.93	9.12
1.00	10.00	10.00	10.00	10.00	10.00

1/ In all cases, flow is from left to right.

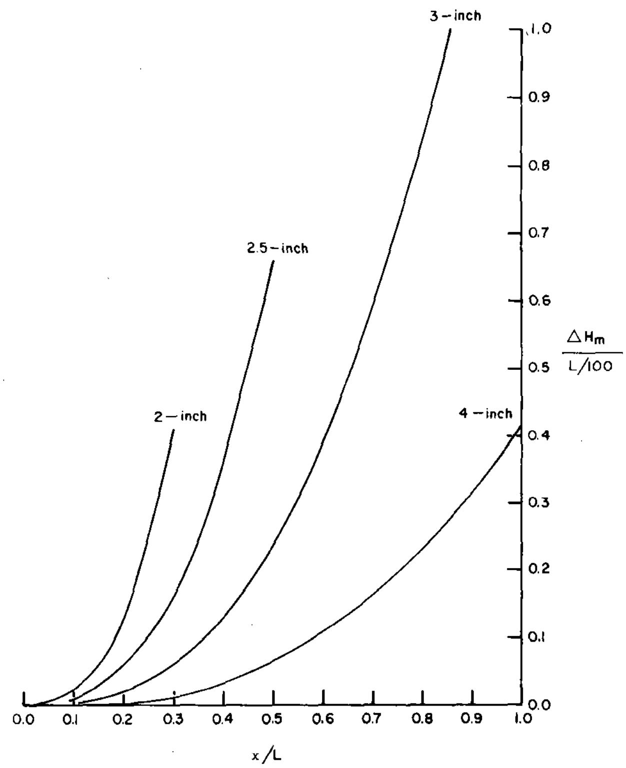

Figure 7–39.—Dimensionless manifold friction curves scaled to represent manifold flow rate (q_m) = 178 gpm through each size of pipe. x = position of point on manifold; L = length of manifold; $\triangle H_m$ = manifold pressure-head variation.

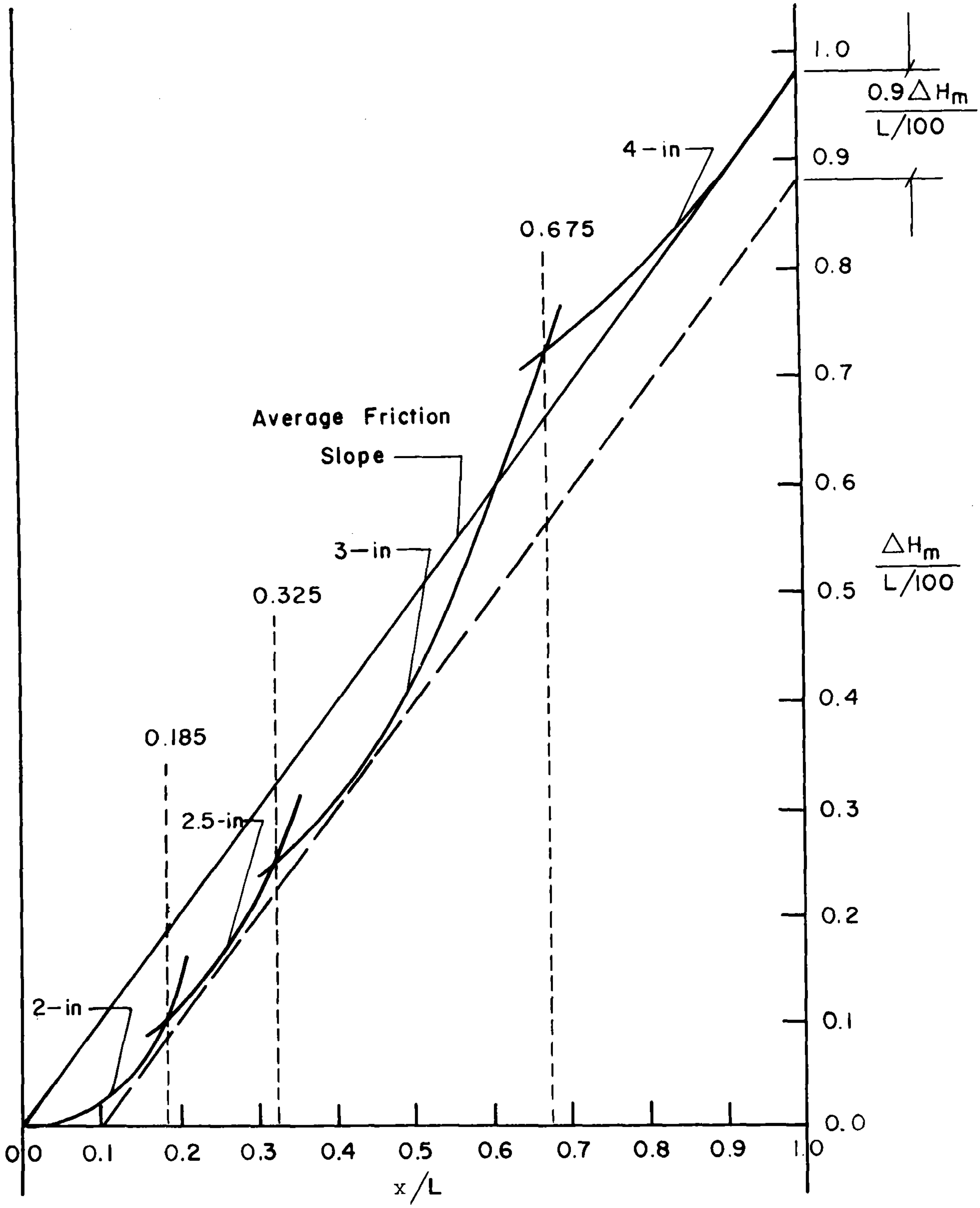

Figure 7–40.—Overlay for design of manifolds (1), (2), and (3) using the general graphical-design method. X = position of point on manifold; L = length of manifold; $\triangle H_m$ = manifold pressure-head variation.

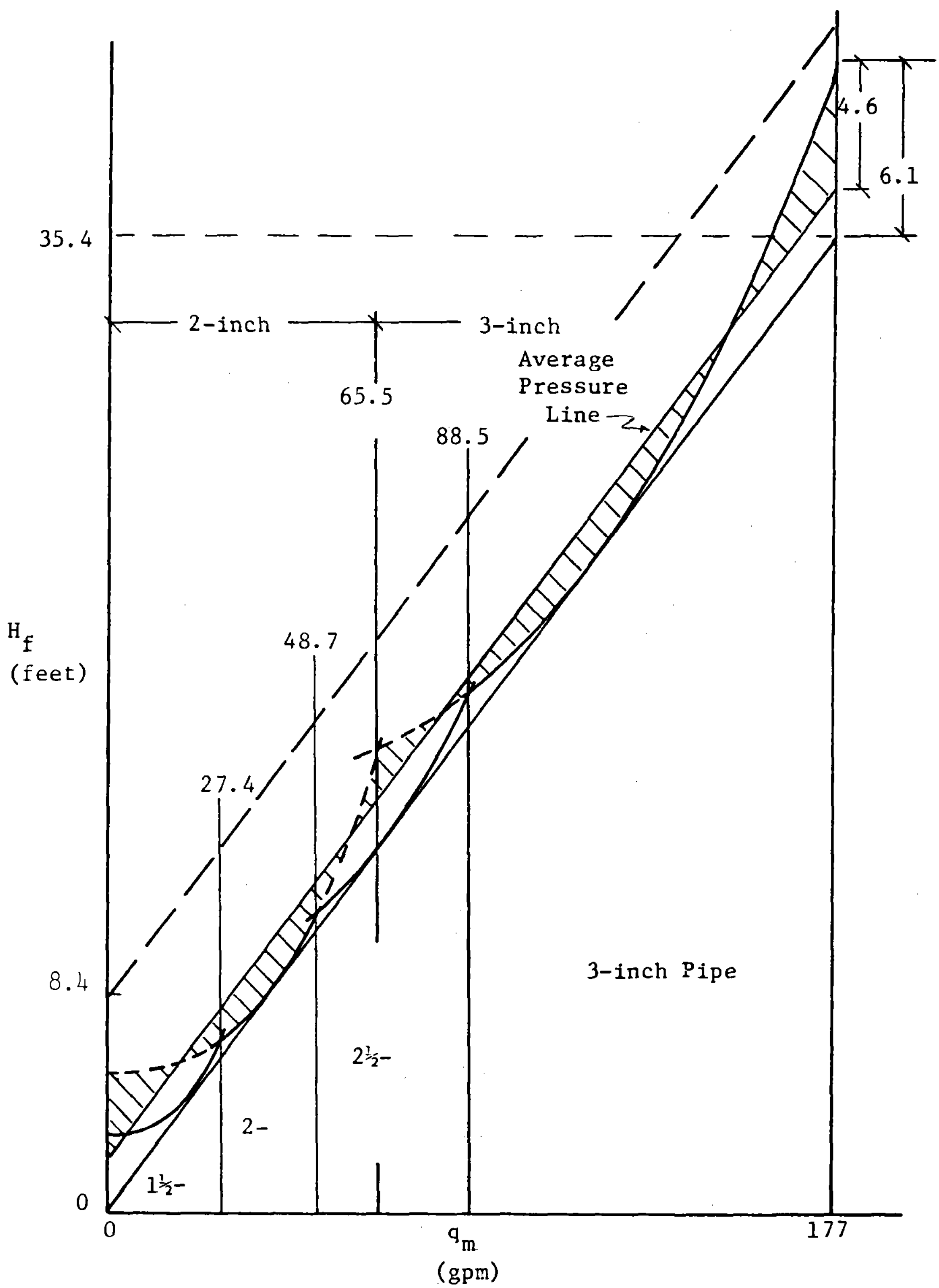

Figure 7–41.—Friction curve overlay to demonstrate graphical method using a standard manifold curve for designing a tapered manifold for a steep slope. H_f = manifold pressure-head loss from pipe friction; q_m = manifold flow rate.

Step 7d—For manifolds running up slope, draw a sloping line for S at x/L = 0 to 0 at x/L = 1. Then draw a horizontal line from j at x/L = 0 to x/L = 1.

Step 8—The most economical design of each manifold is defined by the pairs of lines developed in step 7. The final design is represented by a combination of dimensionless pipe-curve sections representing various pipe diameters and lengths. The procedure for drawing the composite curve is as follows:

1. Start at the origin and trace the friction curve of the smallest permissible pipe from the origin to its intersection with the average friction-slope line.
2. Slide the overlay down until the friction curve of the second pipe size is tangent to the lower limit line. Trace the friction curve from its intersection with the previous friction curve to its intersection with the average friction-slope line.
3. Slide the overlay down, repeating step 2. This time, however, it will be necessary to extend the friction curve well beyond the average friction-slope line.
4. Slide the overlay down until the intersection of the average friction-slope line coincides with the x/L = 1 intercept of the friction curve of the largest pipe to be used. Now trace the friction curve until it intersects with the previous curve segment.

Alternative Graphical-Design Method

The alternative graphical-design method is similar to the general method except that, for rectangular subunits, the set of standard manifold curves presented in figures 7–36 and 7–37 can be used. This eliminates the need for computing and drawing a special set of curves for each set of design conditions. Steps 2, 3, and 4 in the general procedure can be eliminated, and step 1 can be more easily handled by trial and error.

After selection of the proper set of standard manifold curves (see step 6b under Economic-Chart Design Method), the procedure is similar to steps 5 through 8 of the general graphical-design method. Therefore, begin with step 5′ so the comparison can be better visualized.

Step 5′—The standard manifold curves give the manifold pressure-head loss (H_f) for a 0.1-gpm/ft average manifold discharge. Therefore, the allowable manifold-pressure variation [$(\triangle H_m)_a$], feet, and slope along the manifold (S) must be properly scaled to compensate for the difference between the standard curves and the manifold under study. This can be done by equations 7–87 and 7–88.

$$j' = \frac{(\triangle H_m)_a}{k} \qquad \textbf{(7–87)}$$

Where

j' = $(\triangle H_m)_a$ value properly scaled for the manifold under study, feet.
k = scale factor computed by equation 7–80a or 7–80b.

$$S' = \frac{SL_m}{100k} = \frac{Sq_m}{10} = \frac{\triangle El}{k} \qquad \textbf{(7–88)}$$

Where

S' = elevation (from S) properly scaled for the manifold under study, feet.
L_m = actual length of the manifold, feet.
q_m = actual flow rate in the manifold, gallons per minute.
$\triangle El$ = difference in elevation along the manifold, feet.

Step 6′—Place a transparent overlay on the set of standard manifold curves, then trace the horizontal and vertical scales and draw a vertical line at q_m (see figure 7–42).

Step 7′—For level manifolds draw a sloping line through the origin and j' at q_m. Then draw a sloping line parallel to it and passing through $0.9\,j'$ at q_m. (See the solid and dashed lines on figure 7–42.)

Step 7b′—For steeply (down) sloping manifolds (or pairs of manifolds) where $S' > 3j'$, draw a sloping line from the origin to S' at q_m. (This line represents the ground slope drawn to the same scale as the friction curves.) Then draw a second line above and parallel to the ground slope line and passing through $(j' + S')$ at q_m. (See the solid and dashed lines in figure 7–41.)

Step 7c′—For mildly (down) sloping manifolds (or pairs of manifolds) where $S' < 3j'$, draw a sloping line from $0.15S'$ at $q_m = 0$ to $(j' + S')$ at q_m. Then draw a second line below and parallel to it passing through $0.9(j'+S')$ at q_m.

Step 7d'—For manifolds running up slope draw a sloping line from S' at $q_m = 0$ to 0 at q_m. Then draw a horizontal line from j' at $q_m = 0$ to q_m.

Step 8'—This is the same as step 8 for the general graphical-design method.

Estimating Pressure Loss From Pipe Friction

The pressure head loss from pipe friction (H_f) can be estimated from the H_f of a similar manifold (or lateral) by equation 7–89.

$$(H_f)_2 = \frac{L_2}{L_1} \frac{(F_s)_2}{(F_s)_1} \left(\frac{q_2}{q_1}\right)^{1.8} (H_f)_1 \qquad \textbf{(7–89)}$$

Where

$(H_f)_2$ = estimate of the pressure head loss from pipe friction for the manifold, feet.
$(H_f)_1$ = pressure head loss from pipe friction for the original manifold, feet.
L_1 = length of pipe in the original manifold, feet.
L_2 = length of pipe in the manifold for which $(H_f)_2$ is being estimated, feet.
$(F_s)_1$ = friction adjustment factor for the original manifold.
$(F_s)_2$ = friction adjustment factor for the manifold for which $(H_f)_2$ is being estimated.
q_1 = flow rate in the original manifold, gallons per minute.

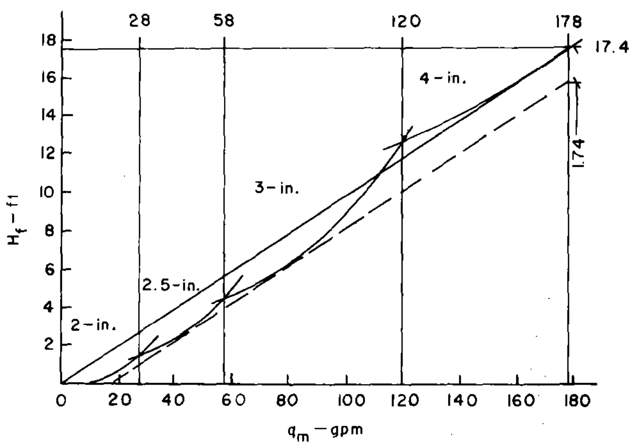

Figure 7–42.—Friction curve overlay demonstrating the graphical solution for using standard manifold curves to design tapered manifolds with a given allowable manifold pressure variation $(\triangle H_m)_a$. H_f = manifold pressure-head loss; q_m = actual flow rate in the manifold.

q_2 = flow rate in the manifold for which $(H_f)_2$ is being estimated, gallons per minute.

The estimated $(H_f)_2$ will be quite accurate as long as the proportional lengths of the various sizes of pipe in tapered manifolds remain constant and the difference between $(F_s)_1$ and $(F_s)_2$ is less than 0.25. If the lengths and subunit shapes are the same, the discharges can vary over a wide range without reducing the accuracy of the $(H_f)_2$ estimate.

Locating the H_m Line and Estimating $\triangle H_m'$

A graphical technique for estimating the manifold head loss can also be used to estimate $\triangle H_m'$ (the amount the manifold inlet pressure [H_m] differs from the lateral-line inlet pressure [h_l]). The $\triangle HH_m'$ is represented by the distance H_m and a line representing the average manifold pressure (H_a) that lies parallel to the slope. The H_a line is positioned so that the areas between it and the friction curve are the same above and below. To aid in locating the H_a line, place the transparent overlay on a piece of graph paper with one heavy grid line. Adjust the overlay and count squares until the above conditions are satisfied as shown in figure 7–41.

Sample Designs for Trickle Irrigation Systems

The following sample designs illustrate the procedures of this handbook.

Drip System

The following drip-system design is for a typical deciduous orchard. The data that should be collected before beginning a design are summarized in the trickle-irrigation-design data sheet (fig. 7–43) and the orchard layout map (fig. 7–44).

In addition to illustrating the general process for designing a drip irrigation system, the example emphasizes the following procedures:

1. Selecting the emitter or emission point spacing (S_e), the lateral spacing (S_l), the duration of application (T_a), the number of stations (N), and the average emitter discharge (q_a) and operating pressure head (h_a).
2. Determining $\triangle H_s$, the allowable variation in pressure head that will produce the desired uniformity of emission.
3. Positioning the manifolds and designing the laterals (with both graphical and numerical solutions) for sloping rows.
4. Designing the manifold and selecting economical pipe sizes for both manifolds and main lines.
5. Computing system capacity and total dynamic operating-head requirements.

Design Factors

Before designing the hydraulic network, the designer must determine the emitter spacing (S_e), average emitter discharge (q_a), average emitter pressure head (h_a), allowable head variation ($\triangle H_s$), and hours of operation per season (Q_t).

The steps for developing these factors are outlined in the trickle-irrigation design factors sheet (fig. 7–45). This data sheet serves as a guide and provides a convenient place to record results of the various trial and final computations.

Field observations of trickle irrigation systems in the same area have shown that the wetted diameter produced by 1.0-gph emitters is between 8 and 9 ft. For a continuous wetted strip, the spacing between emitters in the row should not exceed 80 percent of the wetted diameter. Therefore, for the 24-ft tree spacing, a uniform S_e of 6.0 ft was selected. (Table 7–2 can help predict the areas wetted by an emitter; however, field test data and observations at existing systems are preferable.)

Percent area wetted (P_w).—S_e = 6.0 ft, S_w = 8.5 ft (field data), S_p = 24 ft, S_r = 24 ft, e′ = 4.0

$$P_w = \frac{4.0 \times 6 \times 8.5 \times 100}{24 \times 24} \qquad \textbf{(7-1)}$$

$$P_w = 35.42\%$$

Maximum net depth of application (F_{mn}).—M_{ad} = 30%, WHC = 1.8 in./ft, RZD = 6.0 ft, P_w = 35.42%.

$$F_{mn} = 0.30 \times 1.8 \times 6.0 \times 0.3542 \qquad \textbf{(7-4)}$$

$$F_{mn} = 1.15 \text{ in}$$

Average peak daily transpiration rate (T_d) and seasonal transpiration rate (T_s).—From *Irrigation Water Requirements*:[5] U = 36.74 in., u_m = 8.83 in. for July, u_d = 8.83/31 = 0.28 in., P_s = 78% (field data).

i) $T_d = 0.28[0.78 + 0.15(1.0 - 0.78)]$ **(7–5)**

$T_d = 0.23$ in./day

ii) $T_s = U[P_s + 0.15(0.1 - P_s)]$

$= 36.74[0.78 + 0.15(1.0 - 0.78)]$

$T_s = 29.87$ in./yr

Maximum allowable irrigation interval (days) (I_f).—F_n = 1.15 in., T_d = 0.23 in./day.

$$1.15 = 0.23 I_f \qquad \textbf{(7-6)}$$

$$I_f = 1.15/0.23$$

$$I_f = 5.0 \text{ days}$$

Design irrigation interval (days) (I_f).—I_f = 1 day will be used in developing the design factors, because the actual interval used is a management decision and does not affect the design hydraulics.

Net depth of application (F_n).—T_d = 0.23 in./day, I_f = 1.0 day, assume daily irrigations.

$$F_n = 0.23 \times 1.0 \qquad \textbf{(7-6)}$$

$$F_n = 0.23 \text{ in.}$$

Emission uniformity (EU).—An emission uniformity of 90 percent is a practical design objective for drip systems on relatively uniform topography.

[5]Soil Conservation Service. 1967. Irrigation Water Requirements. U.S. Dep. Agric. Soil Cons. Serv. Tech. Release 21.

I	Project Name--Happy Green Farm	Date-Winter 1978
II	Land and Water Resources	
	a) Field no.	#1
	b) Field area (acres), A	115.68
	c) Average annual effective rainfall (in.), R_e	3.7
	d) Residual stored soil moisture from off-season precipitation (in.), W_s	0
	e) Water supply (gpm)	800
	f) Water storage (acre-ft)	--
	g) Water quality (mmhos/cm), EC_w	1.4
	h) Water quality classification	Good
III	Soil and Crop	
	a) Soil texture	Silt loam
	b) Available water-holding capacity (in./ft), WHC	1.8
	c) Soil depth (ft)	10
	d) Soil limitations	None
	e) Management-allowed deficiency (%), M_{ad}	30
	f) Crop	Almonds
	g) Plant spacing (ft x ft), S_p x S_r	24 x 24
	h) Plant root depth (ft), RZD	6
	i) Percent area shaded (%), P_s	78
	j) Average daily consumptive-use rate for the month of greatest overall water use (in./day), u_d	0.28
	k) Season total crop consumptive-use rate (in.), U	36.74
	l) Leaching requirement (ratio), LR	0
IV	Emitter	
	a) Type	Vortex
	b) Outlets per emitter	1
	c) Pressure head (psi), h	15.0
	d) Rated discharge @ h (gph), q	1.0
	e) Discharge exponent, x	0.42
	f) Coefficient of variability, v	0.07
	g) Discharge coefficient, k_d	0.32
	h) Connection loss equivalent (ft), f_e	0.4

Figure 7–43.—Drip-system data for a deciduous orchard in the Central Valley of California.

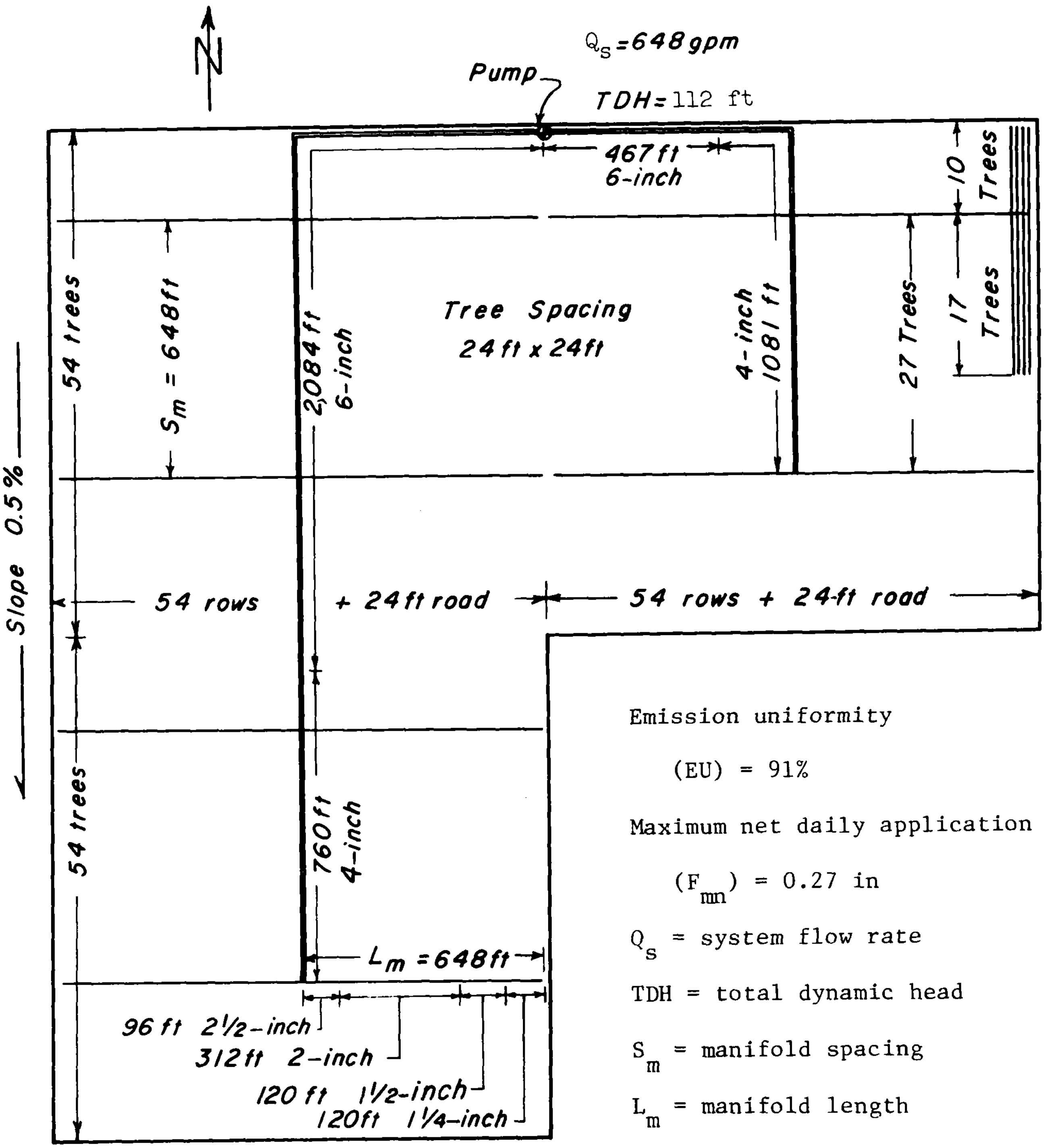

Figure 7–44.—Orchard layout with sample design for a drip irrigation system. (Lateral lines are 0.58-in. polyethylene (PE), manifolds are SDR 26 polyvinyl chloride (PVC), and main lines are SDR 41 PVC.)

I	Project Happy Green Farm	Date-Winter 1978
II	Trial Design	
	a) Emission point layout	St. line
	b) Emitter spacing (ft x ft), S_e x S_l	6 x 24
	c) Emission points per plant, e'	4
	d) Percent area wetted (%), P_w	35.42
	e) Maximum net depth of application (in.), F_{mn}	1.15
	f) Ave. peak-of-application daily transpiration rate (in./day), T_d	0.23
	g) Maximum allowable irrigation interval (days), I_f	5.0
	h) Design irrigation interval (days), I_f	1.0
	i) Net depth of application (in.), F_g	0.23
	j) Emission uniformity (%), EU	90
	k) Gross water application (in.), F_g	0.26
	l) Gross volume of water required per plant per day (gal/day), $F_{(gp/d)}$	93.30
	m) Time of application (hr/day), T_a	23.33
III	Final design	
	a) Time of application (hr/day), T_a	21.0
	b) Design irrigation interval (days), I_f	1.0
	c) Gross water application (in.), F_g	0.26
	d) Average emitter discharge (gph), q_a	1.11
	e) Average emitter pressure head (ft), h_a	44.65
	f) Allowable pressure-head variation (ft), ΔH_s	16.05
	g) Emitter spacing (ft x ft), S_e x S_l	6 x 24
	h) Percent area wetted (%), P_w	35
	i) Number of stations, N	1
	j) Total system capacity (gpm), Q_s	647.37
	k) Seasonal irrigation efficiency (%), E_s	90
	l) Gross seasonal volume (acre/ft), V_i	319.94
	m) Seasonal operating time (hr), Q_t	2,686
	n) Total dynamic head (ft), TDH	112
	o) Emission uniformity (%), EU	91

Figure 7–45.—Drip-system design factors for a deciduous orchard in the Central Valley of California.

Average peak daily transpiration ratio (T_r).—Because the crop is deep rooted and the soil is medium texture, $T_r = 1.00$ as discussed in Gross Water Application under Soil-Plant-Water Considerations.

Leaching requirement ratio (LR_t).—Obtain $EC_w = 1.4$ mmhos/cm from figure 7–43. Obtain min $EC_e = 1.5$ mmhos/cm and max $EC_e = 7$ mmhos/cm from table 7–4 for almonds.

i) $$LR_t = \frac{1.4}{2(7)} = 0.10 \qquad \textbf{(7–17)}$$

ii) Proper leaching should not reduce yield, because $EC_w <$ min EC_e (see equation 7–15).

Gross water application (F_g).—$T_r = 1.00$, $LR_t = 0.1$, $F_n = 0.23$ in./hr, EU = 90%.

i) When the unavoidable losses are greater than the leaching requirement, i.e., $T_r \geq 1/(1.0 - LR_t)$, or

ii) When $LR_t \leq 0.1$, then extra water for leaching is not required during the peak use period and F_g should be computed by equation 7–8a.

iii) $$F_g = \frac{0.23 \times 1.00}{0.90} \qquad \textbf{(7–8a)}$$
$$F_g = 0.26 \text{ in.}$$

Gross volume of water required per plant per day [$F_{(gp/d)}$].—$F_g = 0.26$ in., $S_p = 24$ ft, $S_r = 24$ ft, $I_f = 1$ day.

$$F_{(gp/d)} = \frac{0.623 \times 0.26 \times 24 \times 24}{1} \qquad \textbf{(7–9)}$$
$$F_{(gp/d)} = 93.30 \text{ gal/day}$$

Time of application (T_a).—$F_{(gp/d)} = 93.30$ gal/day, e = 4, $q_a = 1.0$ gph.

i) $$T_a = \frac{93.3}{4 \times 1.0} \qquad \textbf{(7–30)}$$
$$T_a = 23.33 \text{ hr/day} > 21.6$$

ii) Adjusting q_a would bring T_a to within the allowable limits, i.e., 90 percent of 24 = 21.6 hr/day. Because $T_a \cong 23$ hr, one station will be used for the system and the q_a will be increased to give 93.3 gal/day in 21.6 hr or less. (If $T_a \cong 12$ hr, two stations can be used, and if $T_a \cong 6$ hr, four stations can be used.)

iii) For added safety and convenience of operation let $T_a = 21.0$ hr.

Average emitter discharge (q_a).—$T_a = 21.0$ hr, $F_{(gp/d)} = 93.3$ gal/day, e′ = 4.0.

The q_a that will apply the desired volume of water in $T_a = 21.0$ hr is

$$21.0 = \frac{93.3}{4.0\, q_a} \qquad \textbf{(7–30)}$$
$$q_a = \frac{93.3}{4.0 \times 21.0}$$
$$q_a = 1.11 \text{ gph.}$$

Average emitter pressure head (h_a).—q = 1.0 gph, h = 15.0 psi, x = 0.42, $q_a = 1.11$ gph.

i) Compute emitter discharge coefficient (k_d) from the standard emitter flow-rate data given.

$$1.0 = k_d(15.0)^{0.42} \qquad \textbf{(7–20)}$$
$$k_d = 1.0/(15.0)^{0.42}$$
$$k_d = 0.32 \text{ gph/(psi)}^{0.42}$$

ii) The adjusted value of h_a that will give q_a is

$$h_a = \left(\frac{1.11}{0.32}\right)^{1/0.42} \qquad \textbf{(7–31)}$$
$$h_a = 19.33 \text{ psi or } 44.65 \text{ ft.}$$

Allowable pressure-head variation ($\triangle H_s$)—(subunit).—e′ = 4, v = 0.07, $q_a = 1.11$ gph, EU = 90%, $k_d = 0.32$, x = 0.42, $h_a = 19.33$ psi.

i) A subunit is that part of the system beyond the last pressure-regulation point; i.e., if a valve is used to adjust the inlet pressure to a manifold that has no other pressure regulator, the area served by the manifold is a subunit. The object is to limit the pressure variation within a subunit so that actual emission uniformity (EU) will equal or exceed the assumed value of EU.

ii) Rearranging equation 7–33a, the minimum permissible flow, q_n, is

$$q_n = \frac{1.11 \times 90/100}{1.0 - (0.07 \times 1.27/\sqrt{4})}$$
$$q_n = 1.05 \text{ gph.}$$

iii) The minimum permissible pressure head (h_n) that would give q_n is

$$h_a = \left(\frac{q_a}{k_d}\right)^{1/x} \qquad \textbf{(7–31)}$$

$$q_n = q_a\left(\frac{h_n}{h_a}\right)^x \qquad \textbf{(7–38)}$$

$$(\frac{q_n}{q_a}) = (\frac{h_n}{h_a})^x = \; > h_n = h_a(\frac{q_n}{q_a})^{1/x}$$

$$h_n = (\frac{q_a}{k_d})^{1/x}(\frac{q_n}{q_a})^{1/x}$$
$$= (\frac{q_n}{k_d})^{1/x}$$
$$= (1.05/0.32)^{1/0.42}$$
$$h_n = 16.93 \text{ psi.}$$

iv) Therefore, the allowable variation in pressure head for the subunit, $\triangle H_s$, is

$$\triangle H_s = 2.5(19.33 - 16.93) \quad \textbf{(7-34)}$$
$$\triangle H_s = 6.0 \text{ psi or } 13.86 \text{ ft.}$$

Total system capacity (Q_s).—A = 115.7 acres, q_a = 1.11 gph, n = 1.0, S_e = 6 ft, S_l = 24 ft.

$$Q_s = \frac{726 \times 115.7 \times 1.11}{1.0 \times 6 \times 24} \quad \textbf{(7-35b)}$$
$$Q_s = 648 \text{ gpm}$$

Seasonal irrigation efficiency (E_s).—EU = 90%, obtain T_R = 1.00 from table 7-3, LR_t = 0.10.

i) The seasonal irrigation efficiency is the product of EU/100, the expected efficiency of irrigation scheduling, and the inverse of the proportions of the applied water that may be lost to runoff, leaching, or evaporation, or any combination of the three.

ii) Because a commercial scheduling service will be employed for this operation and little runoff, leakage, or evaporation is anticipated:

$$T_R < 1/(1.0 - LR_t).$$

iii) Considering the above, the seasonal irrigation efficiency (E_s) will be

$$E_s = 90\%. \quad \textbf{(7-11)}$$

Gross seasonal volume (V_i).—U = 36.74 in., R_e = 3.7 in., W_s = 0, P_s = 78%, E_s = 90%, A = 115.68 acres, LR_t = 0.1

i) The annual net depth of application [$F_{(an)}$] is

$$F_{(an)} = 33.04[0.78 + 0.15(1.0 - 0.78)] \quad \textbf{(7-10)}$$
$$F_{(an)} = 26.9 \text{ in.}$$

ii) The gross seasonal volume of irrigation water required (V_i) is

$$V_i = \frac{26.9 \times 115.7}{12(1 - 0.1)90/100} \quad \textbf{(7-14)}$$
$$V_i = 320 \text{ acre-ft.}$$

Seasonal operating time (Q_t).—V_i = 320 acre-ft, Q_s = 648 gpm.

$$Q_t = \frac{5{,}430 \times 320}{648} \quad \textbf{(7-37)}$$
$$Q_t = 2{,}682 \text{ hr}$$

Lateral Line Design and System Layout

The procedure for designing a lateral line involves determining the manifold spacing and lateral characteristics, manifold position, lateral inlet pressure, and pressure difference along the laterals.

The procedure for selecting the manifold spacing is presented under Lateral Line Design. It is convenient to have the same spacing throughout the field.

Manifold spacing (S_m).—S_p = 24 ft, S_e = 6 ft, q_a = 1.11 gph, ID = 0.58 in.; from Appendix B, J = 5.73 ft/100 ft; f_e = 0.4 ft; from table 7-6, F = 0.36; $\triangle H_s$ = 16.05 ft, S_p = 24 ft.

i) Inspection of the orchard layout shows that three manifolds, each serving rows of 54 trees, would be the fewest to meet the criteria, i.e., two manifolds for the west 80 acres and one manifold for the east 40 acres.

ii) The difference in pressure head ($\triangle h$) for the level laterals serving 27 trees on either side of each manifold can be calculated as follows:

$$l = 27 \times 24$$
$$l = 648 \text{ ft,}$$

and

$$q_l = \frac{648}{6} \times \frac{1.11}{60} \quad \textbf{(7-62)}$$
$$q_l = 2.00 \text{ gpm.}$$

Taking into account the added roughness from the emitter connections to the laterals,

$$J' = 5.73(\frac{6.0 + 0.4}{6.0}) \quad \textbf{(7-51b)}$$
$$J' = 6.11 \text{ ft/100 ft.}$$

Therefore,

$$\triangle h = h_f = 6.11 \times 0.36 \times 6.48 \qquad \textbf{(7–52)}$$
$$\triangle h = 14.26 \text{ ft.}$$

iii) This $\triangle h$ is considerably greater than 0.5 $\triangle H_s$ and would leave too little margin for differences in pressure head in the manifold.

The lateral length that would produce $h = 0.5\triangle H_s$ and $\triangle H_s = 8.03$ ft can be found directly by using the 14.26-ft head loss computed for the 648-ft-long lateral by equation 7–65b.

$$l = 648\left(\frac{8.03}{14.26}\right)^{1/2.75}$$
$$l = 526 \text{ ft (about 22 trees)}$$

This would give a manifold spacing of

$$S_m = 2 \times 22 \times 24 = 1{,}056 \text{ ft.}$$

Thus, the west 80 acres of the field could be supplied by three manifolds, but the east half would need two manifolds.

iv) Construction was simplified and improved by selecting six equally spaced manifolds so that

$$S_m = 27 \times 24 = 648 \text{ ft.}$$

Thus, l will be 324 ft, and the head difference along each pair of laterals can be estimated by again using the 14.26-ft head loss computed for a 648-ft-long lateral in equation 7–65a.

$$h_f \cong 14.24\left(\frac{324}{648}\right)^{2.75}$$
$$h_f \cong 2.1 \text{ ft.}$$

Graphical determination of manifold position and $\triangle$h.—$J' = 6.11$ ft/100 ft, $F = 0.36$; $S = 0.5\%$, so $\frac{\triangle El}{L/100} = 0.5$; $\triangle H_s = 16.05$ ft; $J'F = 2.20$ ft/100 ft, $L/100 = 6.48$ ft.

i) Now compute J′F for a single lateral equal in length to the manifold spacing (S_m).

This was already done (see previous section, Manifold spacing [S_m], part ii, for l = 648 ft, in which

$$J'F = 6.11 \times 0.36 = 2.20).$$

Thus, 10 on the vertical scale of the overlay represents $J'F = 2.20$.

ii) Place an overlay on figure 7–31 and trace the friction curve (solid line) and the vertical lines on both the right and left sides of the figure, as shown in figure 7–46.

For use of the 0-to-10 dimensionless scale, values from a specific problem must be multiplied by (10/J′F).

iii) Next, draw a line representing the ground surface on the overlay. The left end of this ground-surface line should pass through zero on the vertical scale at x/L = 0 and the right end (at x/L = 1) should pass through

$$\left(\frac{\triangle El}{L/100}\right)' = \frac{10}{2.20} \times 0.5 \qquad \textbf{(7–66)}$$

$$\left(\frac{\triangle El}{L/100}\right)' = 2.27,$$

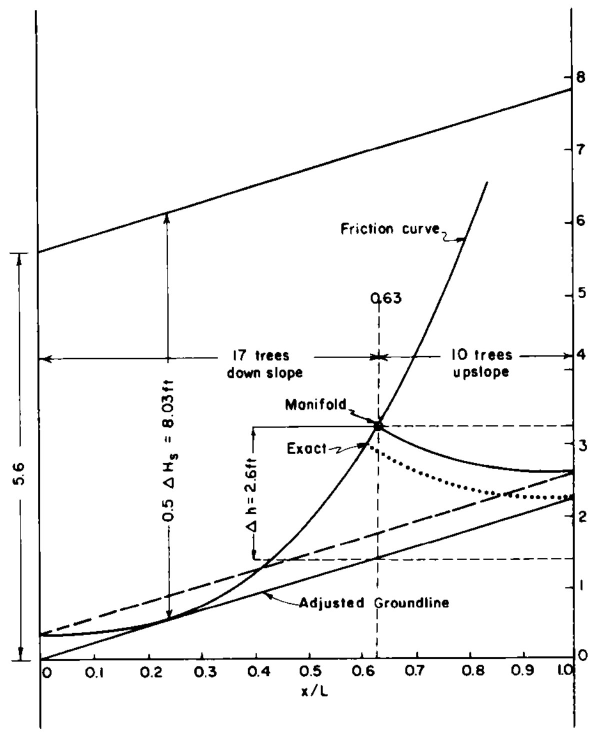

Figure 7–46.—Friction curve overlay to demonstrate graphical solution of manifold positioning and $\triangle$h (difference in pressure head along the lateral). $\triangle H_s$ = allowable subunit pressure-head variation; x = position of manifold along lateral; L = length of lateral.

on figure 7–32, as shown by the dashed sloped line on figure 7–46.

Draw a line parallel to the groundline and tangent to the friction curve. Make sure this line intersects both vertical axes. This is the adjusted groundline, which is the solid straight line on figure 7–46.

A reasonable maximum allowable difference in pressure head along the pair of laterals is 0.5 $\triangle H_s$, as discussed earlier. This is represented by a line parallel to and above the adjusted groundline on the overlay. To represent this allowable pressure head, plot a line the following distance (number of units) above the adjusted groundline as shown in figure 7–46.

$$\text{Units} = \frac{10}{2.2}\left(\frac{0.5 \times 16.05}{6.48}\right) = 5.6$$

iv) To locate the best manifold position, move the overlay down on figure 7–31 until the dashed friction curve coincides with the adjusted groundline at x/L = 1.0.

v) This "exact" manifold position is at x/L = 0.61, where the dashed friction curve intersects the friction curve on the overlay as shown on figure 7–46. This position falls between the 16th and 17th trees from the lower end of the downslope lateral:

at 16 trees,

$$x/L = \frac{16 \times 24}{648} = 0.59,$$

and at 17 trees,

$$x/L = \frac{17 \times 24}{648} = 0.63.$$

The pressure at the upper end of the upslope lateral can be kept above the adjusted groundline by placing the manifold with 17 trees on the downslope laterals and 10 trees on the upslope laterals. To represent this manifold position, move the overlay so that the upslope (dotted) friction curve crosses the friction curve on the overlay at x/L = 0.63 as shown by the solid line in figure 7–46.

vi) The maximum variation in pressure head ($\triangle h$) along the pair of laterals is represented by the maximum distance that the upslope and downslope curves are above the adjusted groundline. Taking values from the overlay for the manifold at x/L = 0.63 and allowing for the scale factor:

$$\frac{\triangle h}{L/100} = \frac{2.20}{10} \times 1.80 \qquad \textbf{(7–66)}$$
$$\frac{\triangle h}{L/100} = 0.40,$$

and

$$\triangle h = 0.40 \times 6.48$$
$$\triangle h = 2.6 \text{ ft}.$$

vii) Because uniform manifold spacings have been chosen and the field has a uniform slope, the manifold position and the head loss in the average lateral, $\triangle h$ = 2.6 ft, will be the same for each subunit.

Numerical determination of manifold position and $\triangle$h.—J = 5.73 ft/100 ft, J′ = 6.11 ft/100 ft, F = 0.36, S = 0.5%; J = 0.5 ft/100 ft, J′F = 2.20 ft/100 ft; x/L = 17 trees/27 trees = 0.63, L/100 = 6.48 ft.

i) Determine J′F as in step 1 of the graphical solution.

ii) Find the tangent location (Y) by

$$Y = (0.5/6.11)^{1/1.75} \qquad \textbf{(7–67)}$$
$$Y = 0.24.$$

iii) Next, solve for the unusable slope component (S′) (see figure 7–34):

$$S' = (0.5 \times 0.24) - 2.20(0.24)^{2.75} \qquad \textbf{(7–68)}$$
$$S' = 0.08.$$

iv) The manifold position can now be located by satisfying equation 7–69. To satisfy the equation, first determine the term on the left:

$$\frac{S - S'}{J'F} = \frac{0.5 - 0.08}{2.20} = 0.19,$$

and then by trial and error find the x/L that balances the equation, i.e.:

$$(0.62)^{2.75} - (1 - 0.62)^{2.75} = 0.20.$$